INVESTIGATION OF THE MAGNESIUM ANODE
THIRD QUARTERLY PROGRESS REPORT
1 JANUARY 1963 TO 1 APRIL 1963

SIGNAL CORPS CONTRACT NO. DA36-039-SC-89082
DEPARTMENT OF ARMY TASK NO. 3A99-09-001-02
U. S. ARMY ELECTRONICS RESEARCH AND DEVELOPMENT LABORATORY
FORT MONMOUTH, NEW JERSEY

THE DOW METAL PRODUCTS COMPANY
DIVISION OF THE DOW CHEMICAL COMPANY
MIDLAND, MICHIGAN

INVESTIGATION OF THE MAGNESIUM ANODE

Report No. 3

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OBJECT

The object of this work is the investigation of magnesium anode behaviors which affect primary cell application.

Prepared by: J. L. Robinson

J. L. Robinson

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I. PURPOSE

The purpose of this research and development contract is the study of the electrochemistry involved in the use of magnesium as an anode in primary battery systems. The studies are a continuation of investigations initiated under Signal Corps Contract No. DA36-039-SC-88912.

II. ABSTRACT

The spontaneous corrosion of magnesium was enhanced by impressed anodic current. The protective film breakdown associated with the anodic current was found to be a rather slow process. The apparent activity of magnesium was sharply reduced by the addition of twenty five atomic percent of cadmium. Anodes of this binary alloy operated at an efficiency of 100% but at a potential of only -0.8 volts versus the saturated calomel electrode. Anodic transient potential data corresponded in general to an electrode under protective film control. All attempts to minimize or eliminate the spontaneous corrosion reaction with $Mg(Ac)_2$ electrolytes failed. The performance of dry cells was poor when salts of aromatic acids were employed for the electrolyte.

III. CONFERENCES

On 21 March 1963 Messrs. D. Wood and J. Murphy of the U. S. Army Electronics Research and Development Laboratory, Fort Monmouth, New Jersey, visited The Dow Metal Products Laboratory at Midland, Michigan to discuss programs for this contract. Dr. M. R. Bothwell and Mr. J. L. Robinson represented The Dow Metal Products Company.

IV. DATA AND DISCUSSION

A. Anode Efficiency Behavior

1. H_2 Evolution Studies

Anode efficiencies are normally determined utilizing the measured applied currents, the anode weight losses, and Faraday's law. The efficiencies with continuously applied current consistently show that the apparent wasteful corrosion rate increases with the current. One explanation(1) for this behavior is that the spontaneous corrosion reaction is the direct reduction of water at anodic sites whose number increases with current due to increasing protective film damage. With this view it follows that the higher corrosion rate should persist after removal of the applied current until the protective film repairs itself.

The above view was jeopardized by intermittent discharge anode efficiencies measured in $MgCl_2$ and $Mg(ClO_4)_2$ electrolytes, Report No. 2. These data indicated that the open circuit spontaneous corrosion was not increased and perhaps even decreased unless the discharge period exceeded ten minutes. To calculate the intermittent discharge open circuit corrosion rates, the contribution of the closed circuit portion of the discharge had to be subtracted from the total weight loss. This closed circuit contribution was based on anode efficiencies or weight losses measured for one hour or more of continuous discharge. This assumes that the film breakdown with applied current was a rapid process. This assumption was consistent with the effect of continuous discharge time on efficiency, Report 2, and anodic transient polarization behavior.(1) However, the assumption had to be in error if the concept of film damage being the cause of the increased corrosion with applied current was valid. That the film breakdown process is relatively slow instead of rapid with $MgCl_2$ electrolyte was demonstrated by the below investigations.

Measurements of anodic hydrogen evolution rates were carried out to better resolve the corrosion behavior during the initial portion of a discharge and the period immediately after removal of the applied current. The evolution rates are a direct measurement of the corrosion rates since hydrogen is the end product of the wasteful reaction. The anode was discharged intermittently and the hydrogen evolved was measured at five minute intervals during both the open circuit and closed circuit portions of the discharge. The usual duration of the on and off periods was twenty minutes but with most runs a forty minute discharge period was included to establish the steady state closed circuit dissolution rate. The hydrogen was collected in a measuring burette over water. An antifoam agent was added to facilitate bubble breakage. Correction of the volumes to standard conditions did not include the effect of the antifoam agent on the vapor pressure of water.

Tables I through VI show the complete data obtained with AZ21X1 anodes, 2 N $MgCl_2$ electrolyte, and varying currents. Examination of these tables and visual observation of the rate of bubble formation indicated

(a) The anode probably never reached a true steady state in time periods employed. However, the average data were reasonably reproducible after completion of the initial discharge cycle.

(b) The spontaneous corrosion rate of the anode is appreciably lower during the initial portion of discharge and tends to pass through a slight maximum prior to approaching a steady state value. This latter is consistent with the observation that the anode efficiency increases marginally with increasing discharge time, Reports 1 and 2.

(c) The anode weight loss equivalent to the total hydrogen collected was equal to the measured weight loss within the experimental error.

The open circuit evolution rate for the initial five minutes was appreciably greater after the first discharge than with subsequent discharges; tables I, II, III. This is probably related to the following observed open circuit corrosion behavior. Figure I is a plot of the open circuit hydrogen evolution rate versus time in the electrolyte with no history of applied current. The sharp maximum in the corrosion rate must indicate that the air formed protective film and the solution formed protective film are markedly different. The initial sharp increase in the evolution rate with exposure time to the electrolyte reflects the instability and breakdown of the air formed film. The slower decline in the rate after the maximum results from formation of a stable film. Unfortunately, potentials were not measured while obtaining the data for Figure I.

The average evolution rates for the last five minutes of the discharge cycle and first five minutes of open circuit are summarized in Table VII. The indicated increase in the initial open circuit corrosion rates with increasing applied currents support the contention that protective film damage is associated with anodic current flow.

The last column of Table VII is a measure of the "Difference Effect."[2] It was obtained by subtraction of the closed circuit rate from the open circuit rate and adjusting to one ampere minute of current passage. Magnesium differs from many metals in that the sign of the "Difference Effect" is usually negative. The reported exceptions[2] have been in acid electrolytes where the open circuit corrosion is extremely high and apparently is controlled by the diffusion rate of the acid. While negative values were obtained with the magnesium chloride electrolytes, Table VII, close examination indicates that positive values might be measured with lower current densities or with shorter discharge periods. A positive "Difference Effect" has been obtained with magnesium acetate electrolyte. The data for the magnesium acetate electrolyte are incomplete and will be reported in the next quarterly report.

In addition to completing the investigation with the magnesium acetate electrolyte it is planned for the next quarter:

(a) To investigate the behavior associated with magnesium perchlorate electrolyte: and

(b) Attempt to demonstrate a positive "Difference Effect" with magnesium chloride electrolyte.

2. Alloy Screening

The inherent activity of magnesium is little affected by normal alloying additions. This activity could be affected by an alloying agent capable of forming a high solid solution alloy. The possibility of altering the anode properties by decreasing the inherent activity was explored with magnesium-lead and magnesium-cadmium binary alloys.

The results of a survey of efficiency and potential behaviors of these alloys in magnesium bromide electrolyte are shown in Table VIII. To calculate the efficiency the equivalent weight was adjusted for the atomic percent of the alloying agent assuming divalent ion formation. The apparent 100 percent efficiency with the high cadmium alloy was confirmed by the lack of visible gas evolution. However, the minus 0.8 volt operating potential of this alloy is essentially that of cadmium rather than magnesium.

Some additional exploratory work was carried out with the lead alloy and sulfuric acid electrolyte. With acid concentrations greater than 80 percent the alloy was passive and stable, but with decreasing concentrations below 80 percent, the corrosion rate activated sharply and the potential slowly. It is planned to survey the behavior of this alloy in a sulfate electrolyte.

B. Potential Behavior

1. Transient Potential Changes

(a) Background-Purpose

Magnesium differs from most metals in that its steady state anodic operating potential is usually little affected by relatively large changes in the current. However, marked transient

potential changes do accompany changes in the current. The magnitude and time duration of the transient voltage change can be significant in the operation of a magnesium primary cell where it is recognized as "Delayed Action".

The potential time plot of Figure 2 is a generalized picture of the transient. It has been studied with bromide electrolytes[1] and tentatively explained in terms of protective film breakdown and repair processes. The basic assumption of the explanation is that under normal conditions only a fraction of the magnesium surface is serving as active anode area while the rest of the surface is shielded by the protective magnesium hydroxide film. With an increase in the anodic current the current density of the active area is increased and the potential moves, as expected, in the passive direction, Figure 2. However, the Mg ions produced by the current rapidly deplete the hydroxide ions at the surface and then pair with the anions of the bulk electrolyte forming soluble magnesium salts. The soluble salts increase the acidity at the interface and the $Mg(OH)_2$ protective film is attacked to create additional active sites. With this increase in the active area the effective current density decreases and the potential activates or recovers until the balance between the breakdown and repair processes are re-established. With the removal of the anodic current the potential activates in the normal fashion, but because of the corresponding decrease rate in the soluble salt formation the protective film can repair itself until the initial steady state is again established.

The object of the work here is to obtain sufficient data with various types of electrolytes and anode compositions to modify or extend the above explanation.

(b) Procedure

The electrolytic cell referred to in Report No I with rectangular 6.8 square centimeters AZ21X1 anodes was employed. The transient curve of Figure 2 was measured with a Sanborn, Model 127, Recorder which has a response time of 0.01 second at a chart speed

of 25 millimeters per second. Power sources of 48 to 600 volts in conjunction with large "Swamping" resistors were employed for constant current sources. In addition to applying anodic current to anodes on open circuit, the current of operating anodes was increased or decreased and the transient measured. In all cases the applied current refers to the increase or decrease in the anodic current. The corrosion current refers to the apparent total anodic current flow, as inferred from weight loss measurements, in the absence of the specified applied current. The potentials were corrected for the IR loss on the basis of the electrolyte's resistivity, Report No I, and a controlled bridge tip to anode spacing of 0.19 centimeters.

Referring to Figure 2 the data tabulated from the transient curves for varying applied and corrosion currents were:

(1) Potential prior to application of anodic current, Point A or B.

(2) The most noble potential observed, Point C.

(3) The difference in potential between Point B and C, ΔE_p.

(4) The apparent steady state potential with the applied current, Point D.

(5) The difference in the potential between Points B and D, steady state polarization.

(6) The most active potential after removal of the applied current, Point E.

(7) The difference in potential between Points D and E, ΔE_A.

(8) The time interval between points B and C.

(9) The time to 80 percent recovery of the potential from C to D.

(10) The total time to reach an apparent new steady state, e.g., the the interval between Points B and D. The citerion for steady state was no significant potential change for a minimum of ten minutes.

(11) The time interval between points D and E.

(c) Results

Six normal $Mg(Ac)_2$ and AZ21X1 anodes were used in the establishment of a standard exposure time of the anode to the environment prior to the transient measurement. Open circuit corrosion rates by weight loss measurement showed that a steady state was not reached during one week exposure, Figure 3. However, there was no significant change in the transient data with open circuit exposure times from 1 to 24 hours, Tables IXA. There was a marked increase in the apparent steady state polarization and a decrease in the transient times when the exposure exceeded 24 hours, Tables IXA and B. The corrosion currents listed in Table IX were extrapolated values from Figure 3. For some tests it was desired to impress a constant anodic current in order to simulate a corrosion rate higher than available with open circuit conditions. For such tests, a one hour exposure time to the six normal electrolyte and to the artificial corrosion current was sufficient to obtain reproducible transient data, Tables X and XI. One hour exposure of the anode to the corrosive environment prior to the transient measurement was adopted as a standard practice.

Transient data for AZ21X1 anodes with varying applied and corrosion currents are tabulated in Tables XII through XVI for 6 N $Mg(Ac)_2$, XVII through XXI for 2 N $Mg(Ac)_2$, and Tables XXII through XXVI for 6 $MgCl_2$ electrolytes. The listed corrosion currents were determined by weight loss measurements and the portion which was artificially applied is shown in the tables. A preliminary attempt was made to establish relationships between the measured polarizations, the transient times and the currents.

With the $MgCl_2$ electrolyte there was no apparent steady state or permanent polarization associated with even the highest applied current, Tables XXII through XXVI. There was an indication of such steady state polarization with the $Mg(Ac)_2$ electrolytes. With the 6 N $Mg(Ac)_2$ electrolyte the apparent polarization was linear with

current, Figure 4. This suggests that the polarization could be just ohmic and that for this electrolyte a resistance of 3.8 ohms rather than the assumed 2.0 ohms should have been used in the IR correction.

While with 6 N $Mg(Ac)_2$ the apparent steady state polarization could be reflecting an error in the IR potential loss correction, this does not appear to be the case with the two normal concentrations. With this latter electrolyte the polarization as measured was definitely not directly related to applied current, Figure 5, but rather an apparent exponential relationship was found, Figure 6. The slope of approximately 0.1 volt for this latter curve would be of the right magnitude for a polarization behavior other than ohmic.

In respect to the transient polarizations the general behavior was common to all three electrolytes. The transient potential changes observed upon application or removal of a given current, ΔE_p and ΔE_A respectively, increased with increasing applied current until a region of maximum values was reached. The applied current required to reach the region of maximum transient potential change was dependent upon the corrosion current. For a given electrolyte the data could best be related by plotting the magnitude of the polarizations as a function the ratio of sum of applied and corrosion currents divided by the corrosion current. This was done for the ΔE_p for figures 7,8, and 9 for the 6 N $Mg(Ac)_2$, the 2 N $Mg(Ac)_2$ and the 6 N $MgCl_2$ electrolytes respectively. With the acetates electrolytes the curve appears to go through 1.0 as the function dictates and with increasing ratios the magnitude of the polarization increases until a plateau region is reached, Figures 7 and 8. This type of behavior is consistent with the proposed general explanation[1] of the transient behavior. It should be noted that the 2 N $Mg(Ac)_2$ data, Table XVII was ignored. The ΔE values appeared to be out of line. It is believed that this was due to the one hour exposure time with this specific electrolyte being too short to establish the stable protective film as discussed previously for the 2 N $MgCl_2$ electrolyte.

The scatter with the chloride data was appreciably less and the curve had some distinctive features, Figure 9. The fact that the curve does not extrapolate back to 1.0 could be indicating that there is some reinforcement of the protective film upon initial application of the current. This could and should occur until the hydroxyl ions available at the interface are consumed. The precipitated $Mg(OH)_2$ reduces the active areas thereby enhancing the polarization. There is no explanation to date for the magnitude of the polarization passing through a maximum with the increasing ratio of the currents.

Inspection of the Tables XII through XVI shows that ΔE_A appears to reach a finite limit at a somewhat lower applied current than that for a similar limit in ΔE_p. The maximum amount of activation (ΔE_A) was independent of electrolyte concentrations, Tables XVI through XXI whereas the maximum passivation (ΔE_p) was highly dependent upon the electrolyte concentration, Figures 7 and 8.

Attempts were made to relate the times needed to complete the various portions of the transient with the magnitude of the potential changes and the currents. Inspection showed that this could not be done with the chloride electrolyte, Tables XXII through XXVI. With the acetate electrolyte and a given corrosion current the times to ΔE_p and 80% recovery did decrease in a rather orderly fashion with increasing applied current. The best single relationship of time with the currents was found for 80% recovery time and is shown in figures 10 and 11. There is no explanation at present for the relationship indicated by the figures. Further, the scatter with the two normal electrolytes, Figure 11, makes this specific relationship doubtful. It is believed that some relationship between the times and currents should exist. The times should be dependent upon the environments at the interface and these environments should be dependent upon the currents.

At this stage no firm conclusion as to the mechanism of the transient behavior can be made. In the next quarter it is planned to include perchlorate electrolytes, additional chloride and acetate concentrations, and at least one other alloy in the measurements.

2. Steady State Polarization

Potentiostatic measurements, as outlined in Reports 1 and 2, were employed for the subsequent polarization curves. It was noted, Report No 2, that the wasteful corrosion reaction could be eliminated with $MgCl_2$ and $Mg(ClO_4)_2$ electrolytes if the anode potential was increased (passive direction) to a sufficiently high value. However, the actual plot of the corrosion current versus the potential was jeopardized by lack of temperature control of the bulk electrolyte. To minimize the temperature fluctuation a polarization curve was determined for $MgCl_2$ at an ambient $32^{\circ}F$. The complete data are shown in Table XXVII and the corrosion current versus potential plot by Figure 12. The temperature control was reasonably good, Table XXVII. The corrosion reaction ceased, as indicated by the approximately 100% anode efficiency and by lack of visible gas evolution, at a potential somewhat greater than -0.75 volts versus saturated calomel. The indicated corrosion currents at potentials more positive than this, Figure 12, represents weight losses incurred during the time needed to establish the steady state. The relationship of the measured potential to the true surface potential is still unknown since no oxygen evolution was observed even at potentials approaching + 5.0 volts.

There was an indication that the behavior observed with the chloride electrolyte could be duplicated with $Mg(Ac)_2$ electrolytes of lower concentration, Report No 2. To check this, polarization curves were measured for 2 N $Mg(Ac)_2$. The data are shown in Table XXVIII and the polarization curves for the applied and corrosion currents are shown by Figures 13 and 14 respectively. The nose in the polarization curve for the corrosion current, Figure 14 was no more pronounced than that previously observed with a four normal

electrolyte, Report No 2. However, the temperature went out of control in most of the individual tests, Table XXVIII.

During the next quarter it is planned to investigate the behavior of both acetate and perchlorate at low temperature. This should minimize the temperature control problem experienced with these electrolytes.

C. Dry Cell Data

The purpose of these cells was to evaluate salts of aromatic acids as electrolytes. In wet cell screening efficiencies in excess of 95% were obtained with such electrolytes[3]. However, these high efficiencies were not translated to the dry cell system, Table XXIX. The steel jacketed cell construction, cathode formulation, and test procedure were described in Report No 1. There are no plans for additional work in dry cells.

V. CONCLUSIONS

The spontaneous corrosion of magnesium is enhanced by impressed anodic current.

The protective film breakdown associated with increased anodic current is a relatively slow process instead of the previously assumed rapid process. Thus, nearly instantaneous measurement of parameters are needed to resolve anodic behavior with changing conditions such as intermittent discharge.

A positive as well as a negative "difference effect" can be measured for magnesium in environments in which the anode is stable.

The apparent activity of magnesium can be greatly reduced by high alloy additions. The reduction in activity mainly reflects modification of the protection film.

The processes which dominate anodic behavior are different with acetate type electrolytes than with chloride type electrolytes.

The usefulness, if any, of electrolytes formulated from salts of aromatic acids is highly limited in dry cells.

VI. TENTATIVE PROGRAM, FOURTH QUARTER

The main emphasis will be investigation of anodic transient behavior including perchlorate electrolytes and different alloys.

The difference effect with acetate and perchlorate electrolytes and with intermittent discharge will be investigated employing hydrogen evolution measurements.

The anodic behavior of magnesium-high lead binary alloy in different environments will be explored.

Additional low temperature anodic polarization curves will be determined.

VII. REFERENCES

1. J. Robinson and P. King, J. Electrochemical Society, 108, 36, 1961
2. A. Thiel and J. Eckell, Z. Electrochemical, 33, 370 (1927)

H_2 EVOLUTION STUDIES - INTERMITTENT DISCHARGE

20 MA/IN^2 - AZ21XI ANODES - 2N $MgCl_2$ ELECT. - 70°F

CC'S H_2 COLLECTED AT 23.6°C & 746.2 MM

	CLOSED CIRCUIT									OPEN CIRCUIT				
TIME INTERVAL → MINUTES	0–5	5–10	10–15	15–20	20–25	25–30	30–35	35–40	TOTAL TIME	0–5	5–10	10–15	15–20	TOTAL TIME
CYCLE														
1	0.8	1.9	2.2	2.0					20	1.0	0.7	0.6	0.7	20
2	1.2	1.4	1.5	1.6					20	0.7	0.4	0.4	0.4	20
3	1.0	1.1	1.3	1.3					20	0.5	0.3	0.3	0.3	20
4	1.0	1.1	1.3	1.4	1.5	1.5	1.4	1.4	40	0.6	0.4	0.3	0.4	20
5	0.9	1.2	1.3	1.4					20	0.4	0.3	0.3	0.3	20
TOTAL COLLECTED	4.9	6.7	7.6	7.7	1.5	1.5	1.4	1.4	120	3.2	2.1	1.9	2.1	100
CC'S - STP	4.21	5.63	6.53	6.62	1.29	1.29	1.20	1.20		2.75	1.80	1.63	1.80	
5 MINUTE RATES														
MEASURED	0.84	1.13	1.31	1.32	1.29	1.29	1.20	1.20		0.55	0.36	0.33	0.36	
APPLIED CURRENT	.71	.71	.71	.71	.71	.71	.71	.71						
ANODE	.13	.43	.60	.61	.58	.58	.49	.49						

APPLIED CURRENT MA : 20.3 FROM COULOMETER - ANODE AREA 6.8 CM^2

ANODE WEIGHT LOSS GRAMS : MEASURED 0.0428 - H_2 EQUIVALENT 0.0394

ANODE EFFICIENCIES FROM H_2 : OVERALL 47.0 %

CLOSED CIRCUIT - AVERAGE 60.3 %

STEADY STATE 59.0 %

FIRST 5 MINUTES 85.0 %

TABLE I

H_2 EVOLUTION STUDIES — INTERMITTENT DISCHARGE

40 MA/IN^2 – AZ21X1 ANODES – 2N $MgCl_2$ ELECT. – 70° F

CC'S H_2 COLLECTED AT 24°C & 752.5 MM

	CLOSED CIRCUIT									OPEN CIRCUIT				
TIME INTERVAL	0	5	10	15	20	25	30	35	TOTAL	0	5	10	15	TOTAL
MINUTES	5	10	15	20	25	30	35	40	TIME	5	10	15	20	TIME
CYCLE														
1	2.9	3.5	3.4	3.2					20	0.8	0.7	0.7	0.6	20
2	2.2	2.7	2.7	1.7					20	0.6	0.4	0.4	0.3	20
3	2.2	2.6	2.7	2.7					20	0.4	0.4	0.3	0.3	20
4	2.3	2.7	2.8	2.8	2.9	2.9	2.8	2.9	40	0.6	0.5	0.4	0.3	20
5	2.3	2.5	2.7	2.7					20	0.4	0.4	0.4	0.4	20
TOTAL COLLECTED	11.9	14.0	14.3	13.1	2.9	2.9	2.8	2.9	120	2.8	2.4	2.2	2.0	100
CC'S – STP	10.5	12.4	12.6	11.2	2.56	2.56	2.48	2.56		2.48	2.12	1.94	1.77	
5 MINUTE RATES														
MEASURED	2.10	2.47	2.53	2.26	2.56	2.56	2.48	2.56		.50	.42	.39	.35	
APPLIED CURRENT	1.38	1.38	1.38	1.38	1.38	1.38	1.38	1.38						
ANODE	.72	1.09	1.15	.98	1.18	1.18	1.10	1.18						

APPLIED CURRENT MA: 39.7 FROM COULOMETER – ANODE AREA 6.8 CM^2

ANODE WEIGHT LOSS GRAMS: MEASURED 0.0735 – H_2 EQIVALENT .0714

ANODE EFFICIENCIES FROM H_2: OVERALL – 50.2 %

CLOSED CIRCUIT – AVERAGE 57.7 %

STEADY STATE 55 %

FIRST 5 MINUTES 66 %

TABLE II

H_2 EVOLUTION STUDIES – INTERMITTENT DISCHARGE

100 MA/IN^2 – AZ21XI ANODES – 2N $MgCl_2$ ELECT. — 70° F

CC'S H_2 COLLECTED AT 25.6°C AND 717.8 MM

	CLOSED CIRCUIT									OPEN CIRCUIT				
TIME INTERVAL	0	5	10	15	20	25	30	35	TOTAL	0	5	10	15	TOTAL
MINUTES	5	10	15	20	25	30	35	40	TIME	5	10	15	20	TIME
CYCLE														
1	5.7	7.7	7.0	7.1					20	1.1	0.6	0.7	0.6	20
2	6.2	6.5	6.5	6.8					20	0.6	0.7	0.5	0.6	20
3	5.8	7.5	6.5	6.5					20	0.7	0.7	0.4	0.6	20
4	6.3	6.9	7.0	7.1	6.9	6.8	6.9	6.9	40	0.8	0.6	0.5	0.5	20
5	6.1	6.3	6.5	6.6					20	0.9	0.6	0.5	0.5	20
TOTAL COLLECTED	30.1	34.9	33.5	34.1	6.9	6.9	6.9	6.9	120	4.1	3.2	2.6	2.8	100
CC'S – STP	26.00	30.14	28.93	29.45	5.96	5.87	5.96	5.96		3.54	2.76	2.25	2.42	
5 MINUTE RATES MEASURED	5.20	6.03	5.79	5.89	5.96	5.87	5.96	5.96		.71	.55	.45	.48	
APPLIED CURRENT	3.48	3.48	3.48	3.48	3.48	3.48	3.48	3.48						
ANODE	1.72	2.55	2.31	2.41	2.48	2.39	2.48	2.48						

APPLIED CURRENT MA: 99.8 FROM COULOMETER – ANODE AREA 6.8 CM^2

ANODE WEIGHT LOSS GRAMS: MEASURED 0.1637 – H_2 EQUIVALENT 0.1621

ANODE EFFICIENCIES FROM H_2: OVERALL 55.8 %

CLOSED CIRCUIT – AVERAGE 58.4 %

STEADY STATE 58.5 %

FIRST 5 MINUTES 67.0 %

TABLE III

H_2 EVOLUTION STUDIES - INTERMITTENT DISCHARGE

200 MA/IN^2 – AZ21X1 ANODES – 2N $MgCl_2$ ELECT. – 70°F

CC'S H_2 COLLECTED AT 23.6°C AND 742.0MM

	CLOSED CIRCUIT									OPEN CIRCUIT				
TIME INTERVAL MINUTES	0–5	5–10	10–15	15–20	20–25	25–30	30–35	35–40	TOTAL TIME	0–5	5–10	10–15	15–20	TOTAL TIME
CYCLE 1	9.8	10.7	13.8	13.7					20	0.8	0.8	0.6	0.7	20
2	12.2	13.2	13.4	13.1					20	1.0	0.7	0.5	0.7	20
3	12.1	13.1	13.0	13.2					20	1.4	0.8	0.7	0.6	20
4	12.3	13.5	13.3	13.1	13.0	12.8	12.8	13.0	40	1.2	0.8	0.7	0.6	20
5	12.4	13.3	13.1	12.9					20	1.0	0.6	0.6	0.6	20
TOTAL COLLECTED	58.8	63.8	66.6	66.0	13.0	12.8	12.8	13.0	120	5.4	3.7	3.1	3.2	100
CC'S - STP	51.20	55.56	57.99	57.47	11.32	11.15	11.15	11.32		4.70	3.22	2.70	2.79	
5 MINUTE RATES MEASURED	10.24	11.11	11.60	11.49	11.32	11.15	11.15	11.32		.94	.64	.54	.56	
APPLIED CURRENT	6.87	6.87	6.87	6.87	6.87	6.87	6.87	6.87						
ANODE	3.37	4.24	4.73	4.62	4.45	4.28	4.28	4.45						

APPLIED CURRENT MA: 197.2 FROM COULOMETER – ANODE AREA 6.8 CM^2

ANODE WEIGHT LOSS GRAMS: MEASURED 0.3030 – H_2 EQUIVALENT 0.3046

ANODE EFFICIENCIES FROM H_2: OVERALL – 58.7 %

CLOSED CIRCUIT – AVERAGE 61.7 %

STEADY STATE 60.0 %

FIRST 5 MINUTES 67.0 %

TABLE IV

H_2 EVOLUTION STUDIES — INTERMITTENT DISCHARGE

400 MA/IN^2 – AZ21X1 ANODES – 2N $MgCl_2$ – 70 °F

CC'S H_2 COLLECTED AT 23.9°C & 740.4 MM

	CLOSED CIRCUIT									OPEN CIRCUIT				
TIME INTERVAL	0	5	10	15	20	25	30	35	TOTAL	0	5	10	15	TOTAL
MINUTES	5	10	15	20	25	30	35	40	TIME	5	10	15	20	TIME
CYCLE														
1	24.5	24.2	23.3	23.0					20	1.4	0.8	0.8	0.6	20
2	23.5	24.4	23.6	23.1					20	1.0	0.9	0.7	0.7	20
3	23.8	24.5	23.7	22.8					20	1.0	0.8	0.6	0.7	20
4	23.9	24.2	23.8	22.6					20	0.9	0.7	0.8	0.6	20
5	23.3	24.6	23.2	22.4					20	1.0	0.8	0.6	0.6	20
TOTAL COLLECTED	119.0	121.9	117.6	113.9					100	5.3	4.0	3.5	3.2	100
CC'S-STP	103.4	105.9	102.1	99.0						4.61	3.48	3.04	2.78	
5 MINUTE RATES														
MEASURED	20.7	21.2	20.4	19.8						.92	.70	.61	.56	
APPLIED CURRENT	13.4	13.4	13.4	13.4										
ANODE	7.3	7.8	7.0	6.4										

APPLIED CURRENT MA: 384.6 FROM COULOMETER – ANODE AREA 6.8 CM^2

ANODE WEIGHT LOSS GRAMS: MEASURED 0.4698 – H_2 EQUIVALENT 0.4608

ANODE EFFICIENCIES FROM H_2: OVERALL 63.1 %

CLOSED CIRCUIT – AVERAGE 65.4 %

STEADY STATE 67.0 %

FIRST 5 MINUTES 64.7 %

TABLE V

H_2 EVOLUTION STUDIES – INTERMITTENT DISCHARGE

650 MA/1.05 IN^2 – AZ21X1 ANODES – 2N $MgCl_2$ ELECT. – 70°F

CC'S H_2 COLLECTED AT 24°C AND 753.4 MM

	CLOSED CIRCUIT			OPEN CIRCUIT				
TIME INTERVAL	0	0	TOTAL	0	5	10	15	TOTAL
MINUTES	5	10	TIME	5	10	15	20	TIME
CYCLE								
1	37.6		20	1.2	0.8	0.9	0.7	20
2		75.7	20	1.1	1.0	0.8	0.6	20
3		76.9	20	1.3	0.8	0.8	0.6	20
4			20	1.3	0.9	0.6	0.6	20
TOTAL COLLECTED	37.6	152.6	80	4.9	3.5	3.1	2.5	80
CC'S - STP				4.33	3.09	2.84	2.21	
5 MINUTE RATES								
AVERAGE		33.59		1.08	.77	.71	.55	
APPLIED CURRENT		22.39						
ANODE		11.20						

APPLIED CURRENT MA: 642.2 FROM COULOMETER – ANODE AREA 6.8 CM^2

ANODE WEIGHT LOSS GRAMS: MEASURED .6064 – ESTIMATED H_2 .597

ANODE EFFICIENCIES FROM H_2: OVERALL 64 %

CLOSED CIRCUIT 66 %

TABLE VI

ANODIC HYDROGEN EVOLUTION RATES

INTERMITTENT DISCHARGE-AZ21X1 ANODES
2N $MgCl_2$

CURRENT	(1) CC'S H_2 / 6.8 CM^2 / 5 MINUTES		(2) Δ CC'S/
MA / 6.8 CM^2	OPEN CIRCUIT	CLOSED CIRCUIT	AMPERES/MINUTE
20	0.55	0.61	-3
40	0.50	0.98	-12
100	0.71	2.41	-17
197	0.94	4.62	-17
385	0.92	6.40	-15
642	1.08	11.2	-16

(1) LAST 5 MINUTES ON CLOSED CIRCUIT
FIRST 5 MINUTES ON OPEN CIRCUIT
(2) "DIFFERENCE EFFECT"

TABLE VII

EFFICIENCY — POTENTIAL BEHAVIORS

HIGH SOLID SOLUTION Mg BINARY ALLOYS

ALLOY AGENT	% WEIGHT	% ATOMIC	EQUIVALENT WEIGHT	(2) POTENTIALS VOLTS vs SATURATED CALOMEL INITIAL OPEN	FINAL OPEN	INITIAL CLOSED	(1) FINAL CLOSED	% ANODE EFF.
Pb	25.1	3.75	15.6	-1.83	-1.74	-1.76	-1.65	53
Cd	25.3	6.85	15.1	-1.68	-1.55	-1.60	-1.40	24.2
Cd	61.2	25.5	23.3	-1.62	-0.84	-0.78	-0.78	103

(1) APPLIED CURRENT 236 MA/2.5 IN^2 FOR 165 MINUTES
(2) 2N $MgBr_2$ ELECTROLYTE

TABLE VIII

ANODIC TRANSIENT STUDIES

ALLOY AZ21X1-95553-6.8cm^2 **ELECTROLYTE** 6N $Mg(Ac)_2$ **TEMPERATURE** °F 70

VARIABLE	EXPOSURE TIME - NO APPLIED CORROSION CURRENT																
TIME - HOURS	.25	.25	.50	.50	1	1	2	2	4	4	7.5	7.5	16	16	24	24	
(1) CURRENTS - MILLIAMPERES																	
I_C - CORROSION	1.5	1.5	2.3	2.3	2.6	2.6	3.8	3.8	4.2	4.2	4.5	4.5	4.3	4.3	3.8	3.8	
I_A - IMPRESSED	24.0	24.0	23.9	24.0	24.0	24.0	23.9	24.0	24.0	24.3	23.9	23.9	24.0	23.9	24.0	24.0	
$I_A + I_C / I_C$																	
(1) POTENTIAL - VOLTS (2)																	
STEADY STATE (I_C) -	1.65	1.63	1.57	1.57	1.58	1.57	1.56	1.56	1.56	1.60	1.57	1.60	1.57	1.57	1.58	1.58	
STEADY STATE ($I_C + I_A$) -	1.45	1.47	1.45	1.49	1.46	1.45	1.46	1.46	1.48	1.50	1.45	1.49	1.47	1.49	1.47	1.50	
TRANSIENT - PASSIVE -	1.10	1.11	1.20	1.25	1.22	1.22	1.22	1.24	1.24	1.22	1.22	1.25	1.26	1.26	1.25	1.28	
TRANSIENT - ACTIVE -	1.77	1.79	1.80	1.79	1.81	1.77	1.77	1.75	1.74	1.80	1.72	1.76	1.75	1.74	1.73	1.76	
(1) POLARIZATION																	
STEADY STATE (DUE TO I_A)	.20	.16	.12	.18	.12	.12	.10	.10	.08	.10	.12	.11	.10	.08	.11	.08	
ΔE_P - PASSIVE	.35	.36	.25	.24	.24	.23	.24	.22	.24	.28	.23	.24	.21	.23	.22	.22	
ΔE_A - ACTIVE	.12	.16	.23	.22	.23	.20	.21	.19	.18	.20	.15	.17	.18	.19	.15	.18	
TIMES - SECONDS																	
TO ΔE_P	.13	.14	.12	.12	.14	.12	.11	.11	.12	.12	.14	.15	.13	.13	.12	.12	
TO 80% RECOVERY	6.9	6.0	4.1	4.4	3.9	3.8	4.2	4.3	4.7	3.1	4.3	4.1	3.7	3.9	4.3	4.3	
TO STEADY STATE $I_A + I_C$	2100	600	7.3	10.6	8.2	6.5	7.9	7.3	7.0	6.5	7.5	8.8	7.0	7.2	6.9	6.7	
TO ΔE_A	1.0	1.5	0.7	1.1	0.6	1.5	1.0	1.1	1.8	0.7	1.3	1.1	1.8	1.6	1.4	1.1	

(1) FOR PRECISE DEFINITION SEE TEXT (2) CORRECTED FOR IR DROP MEASURING CIRCUIT

TABLE IX A

ANODIC TRANSIENT STUDIES

ALLOY AZ21X1-95553-6.8CM^2 ELECTROLYTE 6N $Mg(Ac)_2$ TEMPERATURE ^oF 70

VARIABLE	EXPOSURE TIME - NO APPLIED CORROSION CURRENT																
TIME - HOURS	48	48	72	72	120	120	168	168									
(1) CURRENTS-MILLIAMPERES																	
I_C - CORROSION	2.9	2.9	2.3	2.3	1.6	1.6	1.2	1.2									
I_A - IMPRESSED	23.9	24.0	24.0	23.9	24.0	23.7	23.7	23.6									
$I_A + I_C / I_C$																	
(1) POTENTIAL - VOLTS (2)																	
STEADY STATE (I_C) -	1.57	1.60	1.60	1.59	1.60	1.60	1.58	1.58									
STEADY STATE ($I_C + I_A$) -	1.33	1.42	1.33	1.40	1.36	1.33	1.24	1.16									
TRANSIENT — PASSIVE -	1.07	1.17	1.05	1.12	1.10	1.07	.97	.90									
TRANSIENT — ACTIVE -	1.74	1.75	1.76	1.73	1.75	1.74	1.74	1.70									
(1) POLARIZATION																	
STEADY STATE (DUE TO I_A)	.24	.18	.27	.19	.24	.27	.24	.38									
ΔE_P - PASSIVE	.26	.25	.28	.28	.26	.26	.27	.26									
ΔE_A - ACTIVE	.19	.15	.16	.14	.15	.14	.16	.12									
TIMES - SECONDS																	
TO ΔE_P	.08	.08	.07	.08	.06	.07	.06	.06									
TO 80% RECOVERY	2.1	3.3	.7	2.8	1.8	1.6	.6	.6									
TO STEADY STATE $I_A + I_C$	5.5	7.0	4.4	6.9	4.5	5.1	3.9	3.3									
TO ΔE_A	1.3	0.8	1.0	.8	1.3	1.0	1.2	.8									

(1) FOR PRECISE DEFINITION SEE TEXT (2) CORRECTED FOR IR DROP MEASURING CIRCUIT

TABLE IX B

ANODIC TRANSIENT STUDIES

ALLOY AZ21X1-95553-6.8 cm^2 ELECTROLYTE 6N $Mg(Ac)_2$ TEMPERATURE ^{o}F 70

EXPOSURE TIME TO THE ELECTROLYTE-APPLIED CORROSION ~ 3.0 MA

VARIABLE																	
EXPOSURE TIME - HRS.	1.0	1.0	4	4	16	16	24	24	48	48	72	72					
(1) CURRENTS-MILLIAMPERES																	
I_C - CORROSION	5.5	5.4	5.5	5.5	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4					
I_A - IMPRESSED	31.2	31.5	31.4	31.0	31.5	31.0	31.1	31.4	33.5	34.4	34.4	34.1					
$I_A + I_C / I_C$	6.7	6.8	6.7	6.6	6.8	6.7	6.8	6.8	7.2	7.4	74	7.3					
(1) POTENTIAL - VOLTS (2)																	
STEADY STATE (I_C) -	1.50	1.50	1.53	1.52	1.51	1.53	1.50	1.54	1.53	1.49	1.50	1.54					
STEADY STATE ($I_C + I_A$) -	1.43	1.43	1.47	1.47	1.43	1.49	1.42	1.48	1.43	1.38	1.40	1.47					
TRANSIENT - PASSIVE -	1.20	1.19	1.24	1.23	1.21	1.25	1.21	1.22	1.21	1.14	1.11	1.22					
TRANSIENT - ACTIVE -	1.74	1.75	1.73	—	1.74	1.77	1.71	1.74	1.76	1.71	1.73	1.78					
(1) POLARIZATION																	
STEADY STATE (DUE TO I_A)	.07	.07	.06	.05	.08	.04	.08	.06	.10	.11	.10	.07					
ΔE_P - PASSIVE	.23	.24	.23	.24	.22	.24	.21	.26	.22	.24	.29	.25					
ΔE_A - ACTIVE	.24	.25	.20	—	.23	.24	.21	.20	.24	.22	.23	.24					
TIMES - SECONDS																	
TO ΔE_P	.07	.07	.08	.07	.08	.08	.07	.08	.06	.05	.06	.05					
TO 80% RECOVERY	3.5	3.7	3.4	3.4	3.8	3.9	3.2	3.2	3.4	3.3	3.0	4.1					
TO STEADY STATE $I_A + I_C$	7.0	7.0	5.1	6.5	9.3	7.4	5.5	6.2	5.4	6.2	6.7	6.7					
TO ΔE_A	1.2	1.1	1.1	—	1.3	1.1	1.2	1.1	.09	1.8	1.2	1.8					

(1) FOR PRECISE DEFINITION SEE TEXT (2) CORRECTED FOR IR DROP MEASURING CIRCUIT

TABLE X

ANODIC TRANSIENT STUDIES

ALLOY AZ21XI - 95553 - 6.8cm² ELECTROLYTE 6N Mg(Ac)₂ TEMPERATURE °F 70

VARIABLE	EXPOSURE TIME – APPLIED CORROSION CURRENT ∼ 25 MA																
EXPOSURE TIME – HRS.	.083	.083	.25	.25	.50	.50	1.0	1.0	2	2	4	4	7.5	7.5	16	16	24
(1) CURRENTS-MILLIAMPERES																	
I_C – CORROSION	29.9	30.8	29.6	30.3	29.9	31.1	29.8	28.7	29.7	29.0	28.8	28.6	29.3	29.4	28.8	29.6	30.0
I_A – IMPRESSED	25.3	25.6	26.2	25.1	25.5	24.3	24.6	25.1	25.5	25.0	26.4	25.2	25.6	26.0	25.5	24.5	24.6
$I_A + I_C / I_C$																	
(1) POTENTIAL – VOLTS (2)																	
STEADY STATE (I_C)	-1.43	1.45	1.46	1.47	1.43	1.44	1.46	1.43	1.48	1.46	1.52	1.46	1.51	1.50	1.46	1.41	1.48
STEADY STATE ($I_C + I_A$)	-1.38	1.40	1.40	1.40	1.36	1.37	1.45	1.38	1.45	1.40	1.47	1.41	1.46	1.47	1.42	1.34	[illegible]
TRANSIENT – PASSIVE	-1.34	1.35	1.33	1.35	1.30	1.33	1.34	1.32	1.37	1.33	1.40	1.34	1.39	1.40	1.36	1.28	[illegible]
TRANSIENT – ACTIVE	-1.50	1.55	1.55	1.54	1.50	1.50	1.53	1.52	1.55	1.52	1.56	1.52	1.56	1.57	1.53	1.47	1.47
(1) POLARIZATION																	
STEADY STATE (DUE TO I_A)	.05	.05	.06	.07	.07	.07	.01	.05	.03	.07	.05	.05	.05	.03	.04	.07	.05
ΔE_P – PASSIVE	.05	.05	.07	.05	.06	.04	.11	.06	.08	.06	.07	.07	.07	.07	.06	.06	.06
ΔE_A – ACTIVE	.07	.10	.09	.07	.07	.06	.07	.09	.07	.06	.04	.06	.05	.07	.07	.06	.00
TIMES – SECONDS																	
TO ΔE_P	.29	.22	.32	.31	.25	.28	.30	.27	.30	.40	.34	.35	.32	.32	.30	.28	.35
TO 80% RECOVERY	2.6	—	2.3	1.8	2.1	2.7	1.9	2.4	2.4	2.2	2.3	2.3	2.6	2.3	2.5	2.8	3.2
TO STEADY STATE $I_A + I_C$	4.9	—	3.0	2.6	4.0	3.7	3.0	—	4.8	3.2	3.4	4.2	3.1	3.2	3.4	3.9	4.3
TO ΔE_A	0.6	.8	.6	.6	.5	.6	.7	.8	.6	.6	.5	.6	.7	.7	.6	.7	

(1) FOR PRECISE DEFINITION SEE TEXT (2) CORRECTED FOR IR DROP MEASURING CIRCUIT

TABLE XI

ANODIC TRANSIENT STUDIES

ALLOY AZ21X1-95553-6.8CM^2 ELECTROLYTE 6N $Mg(Ac)_2$ TEMPERATURE °F 72

VARIABLE THE APPLIED CURRENT OPEN CIRCUIT CORROSION ONLY

(1) CURRENTS-MILLIAMPERES																	
I_C - CORROSION	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6			
I_A - IMPRESSED	3.4	3.5	6.2	6.2	12.3	12.3	23.6	23.6	47.7	47.7	72.3	72.3	119	119			
$I_A + I_C / I_C$	1.9	2.0	2.7	2.7	4.4	4.4	7.6	7.6	14.3	14.3	21.1	21.1	39.6	39.6			
(1) POTENTIAL - VOLTS (2)													P	P			
STEADY STATE (I_C)	1.59	1.62	1.60	1.62	1.57	1.57	1.58	1.52	1.59	1.57	1.55	1.58	1.60	1.58			
STEADY STATE ($I_C + I_A$)	1.51	1.51	1.49	1.50	1.48	1.50	1.47	1.41	1.47	1.47	1.35	1.42	1.39	1.38			
TRANSIENT — PASSIVE	1.45	1.46	1.36	1.33	1.29	1.30	1.25	1.17	1.21	1.21	1.08	1.15	1.12	1.11			
TRANSIENT — ACTIVE	1.60	1.60	1.64	1.60	1.67	1.69	1.79	1.73	1.85	1.83	1.82	1.85	1.87	1.87			
(1) POLARIZATION																	
STEADY STATE (DUE TO I_A)	.08	.11	.11	.12	.09	.07	.11	.09	.12	.10	.20	.16	.21	.20			
ΔE_P - PASSIVE	.06	.05	.13	.17	.19	.20	.22	.24	.26	.26	.27	.27	.27	.27			
ΔE_A - ACTIVE	.01	-.02	.04	-.02	.10	.12	.21	.21	.26	.26	.27	.27	.27	.29			
TIMES — SECONDS																	
TO ΔE_P	2.8	3.0	1.40	1.22	.46	.40	.13	.13	.07	.06	.05	.06	.03	.04			
TO 80% RECOVERY	~30.	~20.	9.5	10.4	5.4	5.6	4.7	4.6	3.1	3.2	1.4	2.2	.54	.50			
TO STEADY STATE $I_A + I_C$	~43.	~41.	~30.	~15.	~10.	9.9	7.9	9.3	5.9	6.7	4.0	5.0	2.6	3.9			
TO ΔE_A	.5	.07	.9	.7	2.0	1.4	1.5	1.2	.43	.58	.38	.17	.15	.21			

P - ANODE POLARIZED AFTER TRANSIENT

(1) FOR PRECISE DEFINITION SEE TEXT (2) CORRECTED FOR IR DROP MEASURING CIRCUIT

TABLE XII

ANODIC TRANSIENT STUDIES

ALLOY AZ21XI - 95553 - 6.8 CM^2 ELECTROLYTE 6N $Mg(Ac)_2$ TEMPERATURE °F 72

VARIABLE	THE APPLIED CURRENT								ARTIFICIAL CORROSION OF 3 MA								
(1) CURRENTS-MILLIAMPERES																	
I_C - CORROSION	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5					
I_A - IMPRESSED	3.0	2.9	6.6	6.7	15.3	13.2	31.2	31.3	62.1	62.1	127	127					
$I_A + I_C / I_C$	1.6	1.5	2.2	2.2	3.8	3.4	6.7	6.7	12.3	12.3	24.1	24.1					
(1) POTENTIAL - VOLTS (2)											P	P					
STEADY STATE (I_C)	1.47	1.51	1.51	1.49	1.51	1.47	1.50	1.50	1.49	1.53	1.51	1.53					
STEADY STATE ($I_C + I_A$)	1.46	1.49	1.49	1.49	1.48	1.44	1.43	1.43	1.37	1.43	1.03	1.37					
TRANSIENT - PASSIVE	1.36	1.40	1.32	1.31	1.27	1.23	1.20	1.19	1.10	1.17	.78	1.10					
TRANSIENT - ACTIVE	1.55	1.58	1.62	1.61	1.68	1.65	1.74	1.75	1.79	1.82	1.78	1.81					
(1) POLARIZATION																	
STEADY STATE (DUE TO I_A)	.01	.02	.02	.00	.03	.03	.07	.07	.12	.10	.48	.16					
ΔE_P - PASSIVE	.10	.09	.17	.18	.21	.21	.23	.24	.27	.26	.25	.27					
ΔE_A - ACTIVE	.08	.07	.11	.12	.17	.18	.24	.25	.30	.29	.27	.28					
TIMES - SECONDS																	
TO ΔE_P	1.3	1.5	.64	.65	.20	.22	.07	.07	.03	.04	.03	.02					
TO 80 % RECOVERY	10.2	12.0	6.0	5.9	4.4	4.8	3.5	3.7	2.1	2.0	.3	1.5					
TO STEADY STATE $I_A + I_C$	13.2	—	11.5	10.9	8.8	6.5	7.0	7.0	5.7	5.2	2.9	3.6					
TO ΔE_A	2.3	2.0	2.1	1.6	1.7	1.5	1.2	1.1	.8	1.1	.24	.16					

P - ANODE POLARIZES AFTER COMPLETING TRANSIENT

(1) FOR PRECISE DEFINITION SEE TEXT (2) CORRECTED FOR IR DROP MEASURING CIRCUIT

TABLE XIII

ANODIC TRANSIENT STUDIES

ALLOY AZ21X1 - 95553-6.8CM^2 ELECTROLYTE 6N $Mg(Ac)_2$ TEMPERATURE $^{\circ}F$ 72

VARIABLE THE APPLIED CURRENT ARTIFICIAL CORROSION OF 6 MA

VARIABLE																
(1) CURRENTS-MILLIAMPERES																
I_C - CORROSION	8.7	8.7	8.6	8.6	8.7	8.7	8.7	8.7	8.8	8.8						
I_A - IMPRESSED	5.5	5.7	11.7	11.5	30.9	29.0	58.3	58.3	111.3	109						
$I_A + I_C / I_C$	1.6	1.7	2.4	2.3	4.5	4.3	7.8	7.8	13.7	13.4						
(1) POTENTIAL - VOLTS (2)									P	P						
STEADY STATE (I_C)	1.48	1.50	1.48	1.49	1.49	1.47	1.46	1.47	1.48	1.52						
STEADY STATE ($I_C + I_A$)	1.45	1.49	1.46	1.48	1.39	1.40	1.38	1.39	1.25	1.41						
TRANSIENT - PASSIVE	1.36	1.39	1.31	1.33	1.20	1.22	1.16	1.18	1.04	1.21						
TRANSIENT - ACTIVE	1.54	1.56	1.61	—	1.69	1.66	1.74	1.72	1.75	1.79						
(1) POLARIZATION																
STEADY STATE (DUE TO I_A)	.03	.01	.02	.01	.10	.07	.08	.08	.23	.09						
ΔE_P - PASSIVE	.09	.10	.15	.15	.19	.18	.22	.21	.21	.20						
ΔE_A - ACTIVE	.06	.06	.13	—	.20	.19	.28	.25	.27	.27						
TIMES - SECONDS																
TO ΔE_P	.88	.84	.46	.52	.12	.12	.04	.05	.03	.02						
TO 80% RECOVERY	5.3	5.1	3.7	3.6	3.6	3.8	2.9	2.4	1.1	0.9						
TO STEADY STATE $I_A + I_C$	~125	8.7	5.2	7.9	5.9	7.0	4.8	5.3	3.5	3.5						
TO ΔE_A	1.1	1.2	.8	—	1.35	1.1	1.4	1.0	1.2	1.25						

P -- ANODE POLARIZED AFTER TRANSIENT

(1) FOR PRECISE DEFINITION SEE TEXT (2) CORRECTED FOR IR DROP MEASURING CIRCUIT

TABLE XIV

ANODIC TRANSIENT STUDIES

ALLOY AZ21X1 - 95553 - 6.8 CM^2 ELECTROLYTE 6N $Mg(Ac)_2$ TEMPERATURE °F 72

VARIABLE THE APPLIED CURRENT ARTIFICIAL CORROSION 12 MA

(1) CURRENTS - MILLIAMPERES																	
I_C - CORROSION	14.9	14.9	15.4	15.4	15.0	15.0	15.6	15.6	15.6	15.6	15.1	15.1					
I_A - IMPRESSED	5.6	6.1	11.4	11.2	22.6	22.4	36.9	37.0	58.6	57.8	107	108					
$I_A + I_C / I_C$	1.4	1.4	1.7	1.7	2.5	2.5	3.4	3.4	3.8	3.7	8.7	8.8					
(1) POTENTIAL - VOLTS (2)																	
STEADY STATE (I_C)	1.45	1.50	1.51	1.49	1.49	1.46	1.50	1.52	1.51	1.50	1.50	1.45					
STEADY STATE ($I_C + I_A$)	1.44	1.50	1.50	1.48	1.46	1.42	1.45	1.48	1.43	1.41	1.41	1.34					
TRANSIENT - PASSIVE	1.39	1.44	1.40	1.40	1.33	1.29	1.31	1.33	1.27	1.26	1.24	1.16					
TRANSIENT - ACTIVE	1.51	1.55	1.59	1.57	1.62	1.59	1.65	1.67	1.70	1.66	1.72	1.67					
(1) POLARIZATION																	
STEADY STATE (DUE TO I_A)	.01	.00	.01	.01	.03	.04	.05	.04	.08	.09	.09	.11					
ΔE_P - PASSIVE	.05	.06	.10	.08	.13	.13	.14	.15	.16	.15	.17	.18					
ΔE_A - ACTIVE	.06	.05	.08	.08	.13	.13	.15	.15	.19	.16	.22	.22					
TIMES - SECONDS																	
TO ΔE_P	.63	.44	.60	.56	.37	.32	.19	.20	.09	.09	.04	.03					
TO 80% RECOVERY	4.8	4.6	3.6	3.9	2.7	2.8	2.3	2.6	2.3	1.9	1.15	1.36					
TO STEADY STATE $I_A + I_C$	6.7	6.1	5.6	6.6	5.3	5.5	3.6	5.1	4.1	3.8	2.9	3.1					
TO ΔE_A	.8	1.0	.95	.7	.96	1.16	1.0	1.0	1.1	1.1	1.3	1.2					

(1) FOR PRECISE DEFINITION SEE TEXT (2) CORRECTED FOR IR DROP MEASURING CIRCUIT

TABLE XV

ANODIC TRANSIENT STUDIES

ALLOY AZ21XI-95553-6.8CM^2 ELECTROLYTE 6N $Mg(Ac)_2$ TEMPERATURE ^{o}F 72

VARIABLE THE APPLIED CURRENT ARTIFICIAL CORROSION OF 24 MA

(1) CURRENTS-MILLIAMPERES																	
I_C - CORROSION	29.0	29.0	30.1	30.1	29.4	29.4	28.5	28.5	29.8	29.8	29.1	29.1					
I_A - IMPRESSED	11.3	11.1	19.2	20.1	25.6	25.7	64.4	50.3	85.6	85.5	108	108					
$I_A + I_C / I_C$	1.39	1.38	1.64	1.67	1.87	1.87	3.23	2.77	3.88	3.88	4.72	4.72					
(1) POTENTIAL - VOLTS (2)									P	P	P	P					
STEADY STATE (I_C)	1.49	1.45	1.50	1.50	1.46	1.44	1.45	1.46	1.48	1.52	1.47	1.45					
STEADY STATE ($I_C + I_A$)	1.47	1.42	1.45	1.45	1.45	1.37	1.32	1.38	1.37	1.44	1.28	1.26					
TRANSIENT - PASSIVE	1.43	1.37	1.40	1.39	1.34	1.33	1.22	1.29	1.27	1.34	1.18	1.17					
TRANSIENT - ACTIVE	1.53	1.50	1.54	1.56	1.53	1.50	1.58	1.57	1.60	1.60	1.50	1.53					
P - ANODE POLARIZED AFTER TRANSIENT																	
(1) POLARIZATION																	
STEADY STATE (DUE TO I_A)	.02	.03	.05	.05	.01	.07	.13	.08	.11	.08	.19	.19					
ΔE_P - PASSIVE	.04	.05	.05	.06	.11	.04	.10	.09	.10	.10	.10	.09					
ΔE_A - ACTIVE	.04	.05	.04	.06	.07	.06	.13	.11	.12	.08	.03	.08					
TIMES - SECONDS																	
TO ΔE_P	.40	.47	.38	.38	.30	.28	.13	.18	.08	.09	.06	.05					
TO 80% RECOVERY	2.1	2.4	2.5	2.2	1.9	2.7	1.4	1.7	1.3	1.5	.8	.6					
TO STEADY STATE $I_A + I_C$	3.1	3.2	3.4	3.4	3.0	3.7	2.7	2.4	2.3	2.5	1.9	1.7					
TO ΔE_A	.70	.63	.6	.6	.55	.54	.85	.84	.74	.7	.8	1.0					

(1) FOR PRECISE DEFINITION SEE TEXT (2) CORRECTED FOR IR DROP MEASURING CIRCUIT

TABLE XVI

ANODIC TRANSIENT STUDIES

ALLOY AZ21X1-95553-6.8CM² ELECTROLYTE 2N $Mg(Ac)_2$ TEMPERATURE °F 70

VARIABLE	EXPOSURE TIME - NO APPLIED CORROSION CURRENT																
(1) CURRENTS-MILLIAMPERES																	
I_C - CORROSION	.5	.5	.5	.5	.5	.5	.5	.5	.5	.5	.5	.5	.5	.5	.5	.5	
I_A - IMPRESSED	3.2	3.3	6.8	7.3	11.7	11.7	23.4	24.3	49.7	50.5	73.0	72.7	124	122	219	221	
$I_A + I_C / I_C$	7.4	7.6	14.6	15.6	24.4	24.4	47.8	49.6	100.4	102	147	146.4	249	245	439	443	
(1) POTENTIAL - VOLTS (2)																	
STEADY STATE (I_C)	1.57	1.57	1.57	1.57	1.56	1.57	1.55	1.55	1.54	1.55	1.55	1.55	1.54	1.55	1.56	1.55	
STEADY STATE ($I_C + I_A$)	1.53	1.54	1.53	1.45	1.52	1.53	1.49	1.47	1.13	1.43	1.42	1.39	1.38	1.39	1.39	1.33	
TRANSIENT - PASSIVE	1.14	1.16	.62	.81	.41	.30	+.20	+.03	.12	.42	+.10	.50	.14	.27	+.25	.07	
TRANSIENT - ACTIVE	1.62	1.62	1.65	1.57	1.66	1.67	1.68	1.68	1.55	1.72	1.73	1.74	1.75	1.76	1.77	1.79	
(1) POLARIZATION																	
STEADY STATE (DUE TO I_A)	.04	.03	.04	.12	.04	.04	.06	.08	.41	.12	.13	.16	.16	.16	.17	.22	
ΔE_P - PASSIVE	.39	.38	.91	.64	1.11	1.23	1.69	1.50	1.01	1.01	1.52	.89	1.24	1.12	1.64	1.26	
ΔE_A - ACTIVE	.05	.05	.08	.00	.10	.10	.13	.13	.01	.17	.18	.19	.21	.21	.21	.24	
TIMES - SECONDS																	
TO ΔE_P	.84	.55	.82	.56	.48	.54	.40	.35	.05	.05	.15	.03	.03	.02	.02	.01	
TO 80% RECOVERY	150	230	135	170	75	50	19	4.2	43	55	15	35	27	40	9.3	22	
TO STEADY STATE $I_A + I_C$	950	1230	840	570	580	590	600	725	300	420	325	380	480	480	330	780	
TO ΔE_A	.63	.51	.68	.78	.44	.57	.54	.58	.55	.48	.59	.48	.59	.48	.45	.38	

(1) FOR PRECISE DEFINITION SEE TEXT (2) CORRECTED FOR IR DROP MEASURING CIRCUIT

TABLE XVII

ANODIC TRANSIENT STUDIES

ALLOY AZ21XI-95553 - 6.8 CM^2 (ANP) ELECTROLYTE 2N $Mg(Ac)_2$ TEMPERATURE °F 70

VARIABLE — THE APPLIED CURRENT — ARTIFICIAL CORROSION OF 3 MA

VARIABLE																	
(1) CURRENTS-MILLIAMPERES																	
I_C - CORROSION	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4
I_A - IMPRESSED	3.2	2.5	5.2	6.9	12.9	15.1	30.4	31.0	62.0	62.0	130	130	193	194	242	245	317
$I_A + I_C / I_C$	1.7	1.6	2.2	2.6	3.9	4.4	7.9	8.0	15.2	15.2	30	30	45	45	56	57	73
(1) POTENTIAL - VOLTS (2)																	
STEADY STATE (I_C)	1.52	1.54	1.54	1.55	1.51	1.55	1.54	1.55	1.55	1.55	1.54	1.54	1.55	1.55	1.55	1.55	1.55
STEADY STATE ($I_C + I_A$)	1.49	1.52	1.51	1.51	1.41*	1.49	1.46	1.44	1.42	1.42	1.42	1.37	1.40	1.36	1.41	1.36	1.38
TRANSIENT - PASSIVE	1.40	1.43	1.31	1.27	1.13	1.11	.83	.83	.72	.72	.71	.68	.72	.63	.68	.68	.73
TRANSIENT - ACTIVE	1.55	1.59	1.62	1.63	1.57	1.65	1.68	1.68	1.70	1.70	1.75	—	1.76	1.76	1.78	1.77	1.80
* VOLTAGE HADN'T REACHED SS - 20 MIN.																	
(1) POLARIZATION																	
STEADY STATE (DUE TO I_A)	.03	.02	.03	.04	.10	.06	.08	.11	.13	.13	.12	.17	.15	.19	.14	.19	.17
ΔE_P - PASSIVE	.09	.09	.20	.24	.28	.38	.63	.61	.70	.70	.71	.69	.68	.73	.73	.68	.65
ΔE_A - ACTIVE	.03	.05	.08	.08	.06	.10	.14	.13	.15	.15	.21	—	.21	.21	.23	.22	.25
TIMES - SECONDS																	
TO ΔE_P	.86	.94	.96	.49	.26	.26	.25	.23	.12	.12	.04	.04	.03	.03	.03	.03	.03
TO 80% RECOVERY	140	70	230	34	6.0	115	4.5	1.6	.37	.38	.34	.15	.09	.13	.18	.11	.10
TO STEADY STATE $I_A + I_C$	640	500	460	1100	—	630	490	690	250	520	330	150	290	380	450	250	540
TO ΔE_A	.53	.74	.81	.72	.65	.52	.63	.57	.36	.52	.40	—	.43	.60	.48	.68	.60

(1) FOR PRECISE DEFINITION SEE TEXT (2) CORRECTED FOR IR DROP MEASURING CIRCUIT

TABLE XVIII

ANODIC TRANSIENT STUDIES

ALLOY AZ21X1-95553-6.8CM² ELECTROLYTE 2N $Mg(Ac)_2$ TEMPERATURE °F 70

VARIABLE	THE	APPLIED	CURRENT				ARTIFICIAL	CORROSION	OF 6 MA								
(1) CURRENTS-MILLIAMPERES																	
I_C - CORROSION	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	
I_A - IMPRESSED	5.0	5.1	10.5	10.9	29.2	25.3	65.5	59.8	125	122	226	228	344	338	418	421	
$I_A + I_C / I_C$	1.6	1.6	2.2	2.2	4.3	3.8	8.3	7.7	15	15	26	26	40	39	48	48	
(1) POTENTIAL - VOLTS (2)																	
STEADY STATE (I_C)	1.55	1.55	1.55	1.54	1.54	1.55	1.54	1.54	1.55	1.54	1.55	1.52	1.55	1.55	1.53	1.53	
STEADY STATE ($I_C + I_A$)	1.51	1.52	1.49	1.48	1.43	1.44	1.40	1.41	1.31	1.31	1.42	1.35	1.38	1.39	1.29	1.39	
TRANSIENT - PASSIVE	1.42	1.42	1.31	1.29	1.10	1.11	.80	.83	.60	.58	.73	.70	.75	.75	.64	.79	
TRANSIENT - ACTIVE	1.58	1.60	1.61	1.62	1.65	1.66	1.70	1.71	1.73	1.74	1.77	1.75	1.78	1.79	1.80	1.79	
(1) POLARIZATION																	
STEADY STATE (DUE TO I_A)	.04	.03	.06	.06	.11	.11	.14	.13	.24	.23	.13	.17	.17	. 6	.24	.14	
ΔE_P - PASSIVE	.09	.10	.18	.19	.33	.33	.60	.58	.71	.73	.69	.65	.63	.64	.65	.60	
ΔE_A - ACTIVE	.03	.05	.06	.08	.11	.11	.16	.17	.18	.20	.22	.23	.23	.24	.27	.26	
TIMES - SECONDS																	
TO ΔE_P	.97	.95	.58	.58	.20	.22	.21	.22	.10	.08	.04	.05	.03	.03	.03	.03	
TO 80% RECOVERY	6.9	9	5.4	5.5	4.8	4.8	.50	.63	.25	.28	.22	.38	.12	.12	.07	.15	
TO STEADY STATE $I_A + I_C$	70	380	600	430	430	410	—	350	150	240	130	330	290	340	440	190	
TO ΔE_A	.61	.48	.52	.60	.40	.56	.36	.41	.56	.46	.40	.40	.50	.45	.36	.42	

(1) FOR PRECISE DEFINITION SEE TEXT (2) CORRECTED FOR IR DROP MEASURING CIRCUIT

TABLE XIX

ANODIC TRANSIENT STUDIES

ALLOY AZ21X1-95553-6.8 CM² ELECTROLYTE 2N $Mg(Ac)_2$ TEMPERATURE °F 70

THE APPLIED CURRENT ARTIFICIAL CORROSION OF 12 MA

VARIABLE																	
(1) CURRENTS - MILLIAMPERES																	
I_C - CORROSION	16.1		15.7	15.7	16.6	16.6	16.1	16.1	16.7	16.7	16.3	16.3	16.3	16.3			
I_A - IMPRESSED	4.4		10.3	10.2	22.3	22.8	65.5	65.7	121	121	243	243	413	417			
$I_A + I_C / I_C$	1.4		1.7	1.6	2.3	2.4	5.1	5.1	8.2	8.2	16.0	16.0	26	27			
(1) POTENTIAL - VOLTS (2)																	
STEADY STATE (I_C)	1.55		1.53	1.53	1.54	1.53	1.54	1.52	1.54	1.52	1.52	1.51	1.52	1.54			
STEADY STATE ($I_C + I_A$)	1.51		1.46	1.45	1.42	1.42	1.40	1.38	1.41	1.40	1.37	1.29	1.35	1.37			
TRANSIENT - PASSIVE	1.48		1.36	1.36	1.25	1.22	1.08	1.05	.86	.88	.79	.73	.76	.77			
TRANSIENT - ACTIVE	1.56		1.59	1.59	1.63	1.63	1.69	1.69	1.73	1.73	1.75	1.76	1.78	1.78			
(1) POLARIZATION																	
STEADY STATE (DUE TO I_A)	.04		.07	.08	.12	.11	.14	.14	.13	.12	.15	.22	.17	.17			
ΔE_P - PASSIVE	.03		.10	.09	1.7	.20	.32	.33	.55	.52	.58	.56	.59	.60			
ΔE_A - ACTIVE	.01		.06	.06	.09	.10	.15	.17	.19	.21	.23	.25	.26	.24			
TIMES - SECONDS																	
TO ΔE_P	.85		.68	.73	.33	.30	.15	.15	.12	.10	.06	.06	.04	.04			
TO 80% RECOVERY	~3.0		5.1	4.8	3.9	2.25	1.7	1.7	.43	.44	.21	.20	.11	.11			
TO STEADY STATE $I_A + I_C$	~4.2		~10	48	5.1	~430	25	40	~20	145	105	130	120	105			
TO ΔE_A	.42		.64	.74	.69	.56	.48	.63	.50	.54	.48	.58	.43	.60			

(1) FOR PRECISE DEFINITION SEE TEXT (2) CORRECTED FOR IR DROP MEASURING CIRCUIT

TABLE XX

ANODIC TRANSIENT STUDIES

ALLOY AZ21X1-95553-6.8CM^2 ELECTROLYTE 2N $Mg(Ac)_2$ TEMPERATURE ^{o}F 70

VARIABLE — THE APPLIED CURRENT ARTIFICIAL CORROSION OF 24 MA																	
(1) CURRENTS-MILLIAMPERES																	
I_C - CORROSION	28.5	28.5	28.3	28.3	28.3	28.3	28.8	28.8	28.1	28.1	28.0	28.0					
I_A - IMPRESSED	8.5	8.9	24.1	23.4	47.9	46.9	91	89	249	248	428	428					
$I_A + I_C / I_C$	1.3	1.2	1.9	1.8	2.7	2.6	4.2	4.1	9.7	9.7	161	16.1					
(1) POTENTIAL - VOLTS (2)																	
STEADY STATE (I_C)	1.48	1.49	1.49	1.49	1.47	1.48	1.48	1.48	1.50	1.49	1.48	1.49					
STEADY STATE ($I_C + I_A$)	1.45	1.46	1.43	1.43	1.40	1.40	1.37	1.37	1.41	1.42	1.38	1.42					
TRANSIENT - PASSIVE	1.40	1.40	1.28	1.28	1.17	1.18	1.05	1.07	.99	.99	.85	.89					
TRANSIENT - ACTIVE	1.54	1.54	1.58	1.58	1.63	1.64	1.67	1.68	1.74	1.75	1.76	1.78					
(1) POLARIZATION																	
STEADY STATE (DUE TO I_A)	.03	.03	.07	.07	.07	.08	.11	.11	.09	.07	.10	.07					
ΔE_P - PASSIVE	.05	.06	.15	.15	.23	.22	.32	.30	.42	.43	.53	.53					
ΔE_A - ACTIVE	.06	.05	.09	.09	.16	.16	.19	.20	.24	.26	.30	.29					
TIMES - SECONDS																	
TO ΔE_P	.72	.65	.35	.35	.19	.17	.08	.09	.06	.06	.03	.03					
TO 80% RECOVERY	5.5	4.2	3.1	3.0	3.3	3.1	.53	.52	.32	.33	.10	.14					
TO STEADY STATE $I_A + I_C$	~10	~5	~5	4.5	~20	50	~15	~10	40	40	120	170					
TO ΔE_A	.56	.60	.54	.58	.62	.70	.55	.58	.52	.64	.60	.64					

(1) FOR PRECISE DEFINITION SEE TEXT (2) CORRECTED FOR IR DROP MEASURING CIRCUIT

TABLE XXI

ANODIC TRANSIENT STUDIES

ALLOY AZ21X1 - 95553 - 6.8 CM^2 (ANP)   ELECTROLYTE 6N $MgCl_2$ TEMPERATURE °F 70

THE APPLIED CURRENT—NO APPLIED CORROSION CURRENT

VARIABLE																	
(1) CURRENTS - MILLIAMPERES																	
I_C - CORROSION	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
I_A - IMPRESSED	3.0	3.5	6.4	6.5	12.9	12.9	21.3	25.6	52.0	52.0	75.2	75.5	124	126	249	248	463
$I_A + I_C / I_C$	1.1	1.2	1.3	1.3	1.6	1.6	2.1	2.3	3.6	3.6	4.8	4.8	7.2	7.3	13.5	13.5	24
(1) POTENTIAL - VOLTS (2)																	
STEADY STATE (I_C)	1.64	1.65	1.65	1.65	1.65	1.65	1.65	1.64	1.65	1.64	1.64	1.64	1.64	1.64	1.65	1.65	1.64
STEADY STATE ($I_C + I_A$)	1.64	1.65	1.64	1.64	1.64	1.64	1.63	1.64	1.63	1.64	1.63	1.63	1.64	1.64	1.64	1.64	1.6[illegible]
TRANSIENT - PASSIVE	1.63	1.63	1.62	1.63	1.61	1.60	1.55	1.54	1.34	1.38	1.19	1.20	1.01	1.01	1.01	1.00	1.1[illegible]
TRANSIENT - ACTIVE	1.65	1.65	1.66	1.65	1.66	1.66	1.67	1.68	1.71	1.71	1.72	1.72	1.75	1.75	1.78	1.78	1.81
(1) POLARIZATION																	
STEADY STATE (DUE TO I_A)	.00	.00	.01	.01	.01	.01	.02	.00	.02	.00	.01	.01	.00	.00	.01	.01	.02
ΔE_P - PASSIVE	.01	.02	.02	.01	.03	.04	.08	.10	.29	.26	.44	.43	.63	.63	.63	.64	.51
ΔE_A - ACTIVE	.01	.00	.01	.00	.01	.01	.02	.04	.06	.07	.08	.08	.11	.11	.13	.13	.17
TIMES - SECONDS																	
TO ΔE_P	.03	.03	.03	.03	.04	.03	.03	.03	.04	.05	.10	.07	.09	.10	.02	.02	<.01
TO 80% RECOVERY	—	—	<1	<1	.33	.65	.63	2.7	.27	.75	.36	.35	.28	.30	.10	.14	.22
TO STEADY STATE $I_A + I_C$	—	—	1.0	2.3	1.2	2.0	~5	—	3.1	~10	~10	~10	2.5	5.8	4.9	5.7	~20
TO ΔE_A	—	—	<.01	<.01	<.01	<.01	.03	.01	.04	.04	.05	.07	.07	.06	.07	.07	.06

(1) FOR PRECISE DEFINITION SEE TEXT   (2) CORRECTED FOR IR DROP MEASURING CIRCUIT

TABLE XXII

ANODIC TRANSIENT STUDIES

ALLOY AZ21XI-95553-6.8CM² ELECTROLYTE 6N $MgCl_2$ TEMPERATURE °F 70

VARIABLE THE APPLIED CURRENT ARTIFICIAL CORROSION OF 3 MA

VARIABLE																	
(1) CURRENTS - MILLIAMPERES																	
I_C - CORROSION	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	
I_A - IMPRESSED	2.4	2.6	6.3	6.4	23.5	23.8	48.0	48.2	77.3	78.0	125	125	253	260	437	433	
$I_A + I_C / I_C$	1.1	1.1	1.3	1.3	2.1	2.1	3.2	3.2	4.5	4.5	6.7	6.7	12.6	12.7	20.6	20.5	
(1) POTENTIAL - VOLTS (2)																	
STEADY STATE (I_C)	1.65	1.65	1.65	1.65	1.65	1.65	1.64	1.65	1.65	1.64	1.64	1.64	1.64	1.65	1.64	1.64	
STEADY STATE ($I_C + I_A$)	1.65	1.65	1.65	1.65	1.65	1.64	1.64	1.64	1.63	1.63	1.62	1.62	1.62	1.61	1.62	1.62	
TRANSIENT - PASSIVE	1.64	1.64	1.63	1.63	1.57	1.57	1.44	1.45	1.24	1.27	1.02	1.03	1.01	1.01	1.07	1.09	
TRANSIENT - ACTIVE	1.65	1.66	1.66	1.66	1.68	1.68	1.70	1.70	1.72	1.71	1.74	1.72	1.77	1.77	1.79	1.80	
(1) POLARIZATION																	
STEADY STATE (DUE TO I_A)	.00	.00	.00	.00	.00	.01	.00	.01	.02	.01	.02	.02	.02	.04	.02	.02	
ΔE_P - PASSIVE	.01	.01	.02	.02	.08	.07	.20	.19	.39	.36	.60	.59	.61	.60	.55	.53	
ΔE_A - ACTIVE	.00	.01	.01	.01	.03	.03	.06	.05	.07	.07	.10	.08	.13	.12	.15	.16	
TIMES - SECONDS																	
TO ΔE_P	—	.03	.03	.03	.03	.02	.02	.03	.06	.06	.10	.10	.03	.03	<.01	.005	
TO 80% RECOVERY	—	—	~.3	~.4	.3	.37	.27	.20	.30	.24	.28	.27	.08	.09	.04	.05	
TO STEADY STATE $I_A + I_C$	—	.2	.6	.8	1.1	2.1	3.2	2.6	4.6	~4	1.5	1.3	~5	~5	27	30	
TO ΔE_A	—	.03	.02	.03	.02	.03	.04	.03	.05	.05	.06	.05	.07	.07	.07	.07	

(1) FOR PRECISE DEFINITION SEE TEXT (2) CORRECTED FOR IR DROP MEASURING CIRCUIT

TABLE XXIII

ANODIC TRANSIENT STUDIES

ALLOY AZ21XI-95553-6.8CM^2 ELECTROLYTE 6N $MgCl_2$ TEMPERATURE °F 70

VARIABLE	THE APPLIED CURRENT							ARTIFICIAL CORROSION OF 6 MA									
(1) CURRENTS-MILLIAMPERES																	
I_C - CORROSION	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24
I_A - IMPRESSED	6.3	6.2	10.7	10.7	17.7	17.7	43.4	42.9	56.7	56.9	118	118	246	246	375	374	464
$I_A + I_C / I_C$	1.3	1.3	1.4	1.4	1.7	1.7	2.8	2.8	3.3	3.3	5.9	5.9	11.2	11.2	16.6	16.5	20.3
(1) POTENTIAL - VOLTS (2)																	
STEADY STATE (I_C)	1.64	1.64	1.64	1.64	1.62	1.53	1.63	1.62	1.64	1.63	1.63	1.63	1.63	1.63	1.64	1.63	1.63
STEADY STATE ($I_C + I_A$)	1.64	1.64	1.64	1.64	1.62	1.62	1.63	1.63	1.63	1.63	1.62	1.62	1.63	1.63	1.63	1.61	[illegible]
TRANSIENT — PASSIVE	1.63	1.63	1.62	1.62	1.57	1.57	1.46	1.48	1.41	1.40	1.13	1.13	.99	.97	1.06	1.06	[illegible]
TRANSIENT — ACTIVE	1.65	1.65	1.65	1.66	1.65	1.65	1.68	1.68	1.69	1.68	1.74	1.73	1.77	1.77	1.79	1.77	1.80
(1) POLARIZATION																	
STEADY STATE (DUE TO I_A)	.00	.00	.00	.00	.00	.01	.00	-.01	.01	.00	.01	.01	.00	.00	.01	.02	.01
ΔE_P - PASSIVE	.01	.01	.02	.02	.05	.05	.17	.15	.22	.23	.49	.49	.64	.66	.57	.55	.53
ΔE_A - ACTIVE	.01	.01	.01	.02	.03	.02	.05	.06	.05	.05	.11	.10	.14	.14	.15	.14	.17
TIMES — SECONDS																	
TO ΔE_P	.04	.03	.03	.03	.04	.03	.03	.02	.03	.03	.09	.09	.03	.03	.005	<.01	<.01
TO 80% RECOVERY	—	—	~.3	~.5	1.9	1.7	.47	~.3	.26	.53	.28	.31	.09	.10	.04	.06	.06
TO STEADY STATE $I_A + I_C$	1.1	~3	1.1	1.5	3.1	2.8	4.6	4.4	~5	3.2	2.5	3.8	3.6	—	~10	~6	~5
TO ΔE_A	.02	.03	.02	<.01	.01	.01	.05	.04	.05	.04	.07	.06	.06	.06	.06	.08	.06

(1) FOR PRECISE DEFINITION SEE TEXT (2) CORRECTED FOR IR DROP MEASURING CIRCUIT

TABLE XXIV

ANODIC TRANSIENT STUDIES

ALLOY AZ21X1 - 95553-6.8 CM² **ELECTROLYTE** 6N $MgCl_2$ **TEMPERATURE °F** 70

THE APPLIED CURRENT ARTIFICIAL CORROSION OF 12 MA

VARIABLE																	
(1) CURRENTS - MILLIAMPERES																	
I_C - CORROSION	34	34	34	34	34	34	34	34	34	34	34	34					
I_A - IMPRESSED	10.6	9.8	22.5	23.2	53.6	53.0	115	116	236	236	448	450					
$I_A + I_C / I_C$	1.3	1.3	1.7	1.7	2.6	2.6	4.4	4.5	7.9	7.9	14.2	14.2					
(1) POTENTIAL -- VOLTS (2)																	
STEADY STATE (I_C)	1.64	1.64	1.64	1.64	1.64	1.64	1.64	1.64	1.64	1.64	1.64	1.63					
STEADY STATE ($I_C + I_A$)	1.64	1.64	1.64	1.64	1.64	1.63	1.64	1.63	1.64	1.64	1.62	1.58					
TRANSIENT -- PASSIVE	1.62	1.62	1.59	1.59	1.48	1.48	1.24	1.24	.99	1.00	1.07	1.05					
TRANSIENT - ACTIVE	1.65	1.65	1.66	1.66	1.69	1.68	1.75	1.74	1.76	1.76	1.80	1.80					
(1) POLARIZATION																	
STEADY STATE (DUE TO I_A)	.00	.00	.00	.00	.00	.01	.00	.01	.00	.00	.02	.05					
ΔE_P - PASSIVE	.02	.02	.05	.05	.16	.15	.40	.39	.65	.64	.55	.53					
ΔE_A - ACTIVE	.01	.01	.02	.02	.05	.04	.11	.10	.12	.12	.16	.17					
TIMES - SECONDS																	
TO ΔE_P	.03	.04	.03	.03	.03	.02	.06	.06	.05	.05	.01	<.01					
TO 80% RECOVERY	~1.4	~.8	.55	.26	.46	.22	.23	.23	.12	.12	.05	.08					
TO STEADY STATE $I_A + I_C$	~3.0	~2.5	1.5	1.5	~5	4.5	3.4	~5	3.2	1.0	4.1	5.4					
TO ΔE_A	.02	.04	.03	.02	.06	.04	.05	.06	.09	.06	.06	.06					

(1) FOR PRECISE DEFINITION SEE TEXT (2) CORRECTED FOR IR DROP MEASURING CIRCUIT

TABLE XXV

ANODIC TRANSIENT STUDIES

ALLOY AZ21XI-95553-6.8CM² **ELECTROLYTE** 6N $MgCl_2$ **TEMPERATURE** °F 70

VARIABLE THE APPLIED CURRENT ARTIFICIAL CORROSION OF 24 MA

VARIABLE												
(1) CURRENTS - MILLIAMPERES												
I_C - CORROSION	50	50	50	50	50	50	50	50	50	50	50	50
I_A - IMPRESSED	17.4	17.8	39.4	39.5	61.9	62.8	109	109	230	228	443	438
$I_A + I_C / I_C$	1.3	1.4	1.8	1.8	2.2	2.3	3.2	3.2	5.6	5.6	9.8	9.8
(1) POTENTIAL - VOLTS (2)												
STEADY STATE (I_C)	1.64	1.63	1.63	1.63	1.65	1.64	1.65	1.65	1.64	1.64	1.64	1.63
STEADY STATE ($I_C + I_A$)	1.64	1.64	1.63	1.64	1.63	1.63	1.64	1.64	1.64	1.64	1.63	1.62
TRANSIENT - PASSIVE	1.62	1.62	1.56	1.57	1.51	1.50	1.37	1.36	1.08	1.01	.98	1.00
TRANSIENT - ACTIVE	1.65	1.64	1.67	1.67	1.69	1.68	1.73	1.73	1.77	1.77	1.80	1.79
(1) POLARIZATION												
STEADY STATE (DUE TO I_A)	.00	-.01	.00	-.01	.02	.01	.01	.01	.00	.00	.01	.01
ΔE_P - PASSIVE	.02	.02	.07	.07	.12	.13	.27	.28	.56	.63	.65	.62
ΔE_A - ACTIVE	.01	.01	.04	.04	.04	.04	.08	.08	.13	.13	.16	.16
TIMES - SECONDS												
TO ΔE_P	.03	.04	.03	.03	.02	.03	.03	.03	.08	.09	.03	.03
TO 80% RECOVERY	~.7	—	.3	.2	.25	.15	.17	.17	.28	.32	.07	.07
TO STEADY STATE $I_A + I_C$	1.6	—	2.7	1.5	2.7	3.6	4.0	4.2	4.1	~5	1.6	1.4
TO ΔE_A	<.01	<.01	<.01	<.01	.06	.05	.06	.06	.07	.08	.07	.06

(1) FOR PRECISE DEFINITION SEE TEXT (2) CORRECTED FOR IR DROP MEASURING CIRCUIT

TABLE XXVI

POTENTIOSTATIC DATA - LOW TEMPERATURE - 32° F
AZ21XI ANODES - 6.8 CM^2 - 8N $MgCl_2$

Mg ELECTRODE POTENTIAL VOLTS vs SAT. CAL.	FINAL TEMP. °F	TEST TIME MINUTES	(1) CURRENTS MILLIAMPERES I_{am}	I_{af}	I_a	I_{ca}	I_t	ANODE EFF. %
+ 4.9	34	80	420	200	219	1	220	99.5+
+ 1.9	36	140	300	190	222	4	226	98
+ 0.83	33	95	375	320	342	8	350	97.7
− 0.17	32	95	460	335	344	12	356	96.7
− 0.77	36	80	695	395	441	55	496	89
− 1.26	39	60	715	530	529	158	687	77
− 1.48	34	70	700	445	488	168	656	74.5
− 1.56	32	85	430	340	367	158	525	70
− 1.58	32	180	190	160	172	83	255	67.4
− 1.60	34	300	110	95	102	52	154	66.3

(1) I_{am} = MAXIMUM APPLIED CURRENT, I_{af} = FINAL AP[illegible] CURRENT, I_a = AVERAGE [illegible] CURRENT, I_t = APPARENT TOTAL CURRENT FROM WT. LOSS, I_{ca} = APPARENT [illegible] CORROSION CURR[illegible]

[illegible] XXVII

POTENTIOSTATIC DATA

AZ21X1 ANODES - 2N $Mg(Ac)_2$ - 70°F

Mg ELECTRODE (1) POTENTIAL VOLTS vs SAT. CAL.	FINAL TEMP. °F	TEST TIME MINUTES	(2) CURRENTS MILLIAMPERES I_{am}	I_{af}	I_a	I_{ca}	I_t	ANODE EFF. %
+ 3.3	96	10	—	—	3700	868	4568	81
+ 2.8	150	12	3300	3300	2635	644	3279	80.4
+ 2.2	142	12	3200	3200	2640	662	3302	80
+ 2.0	129	14	2750	2750	2125	570	2895	78.8
+ 1.0	126	25	2000	1850	1408	415	1823	77.3
0	102	35	1350	1100	870	346	1216	71.7
− 0.50	96	40	970	970	814	339	1153	70.5
− 0.75	98	48	970	970	778	393	1171	66.5
− 1.00	93	60	650	590	594	505	1099	54.2
− 1.15	89	85	490	420	427	331	758	56.4
− 1.25	—	110	330	330	307	149	456	67.3
− 1.40	77	390	58	54	48.3	6.5	54.8	88.1
− 1.50	—	1440	14	13	12.6	3.1	15.7	80.2

(1) NOT CORRECTED FOR IR DROP

(2) I_{am} = MAXIMUM APPLIED CURRENT, I_{af} = FINAL APPLIED CURRENT, I_a = AVERAGE APPLIED CURRENT, I_t = APPARENT TOTAL CURRENT FLOW FROM WT. LOSS, I_{ca} = APPARENT AVERAGE CORROSION CURRENT

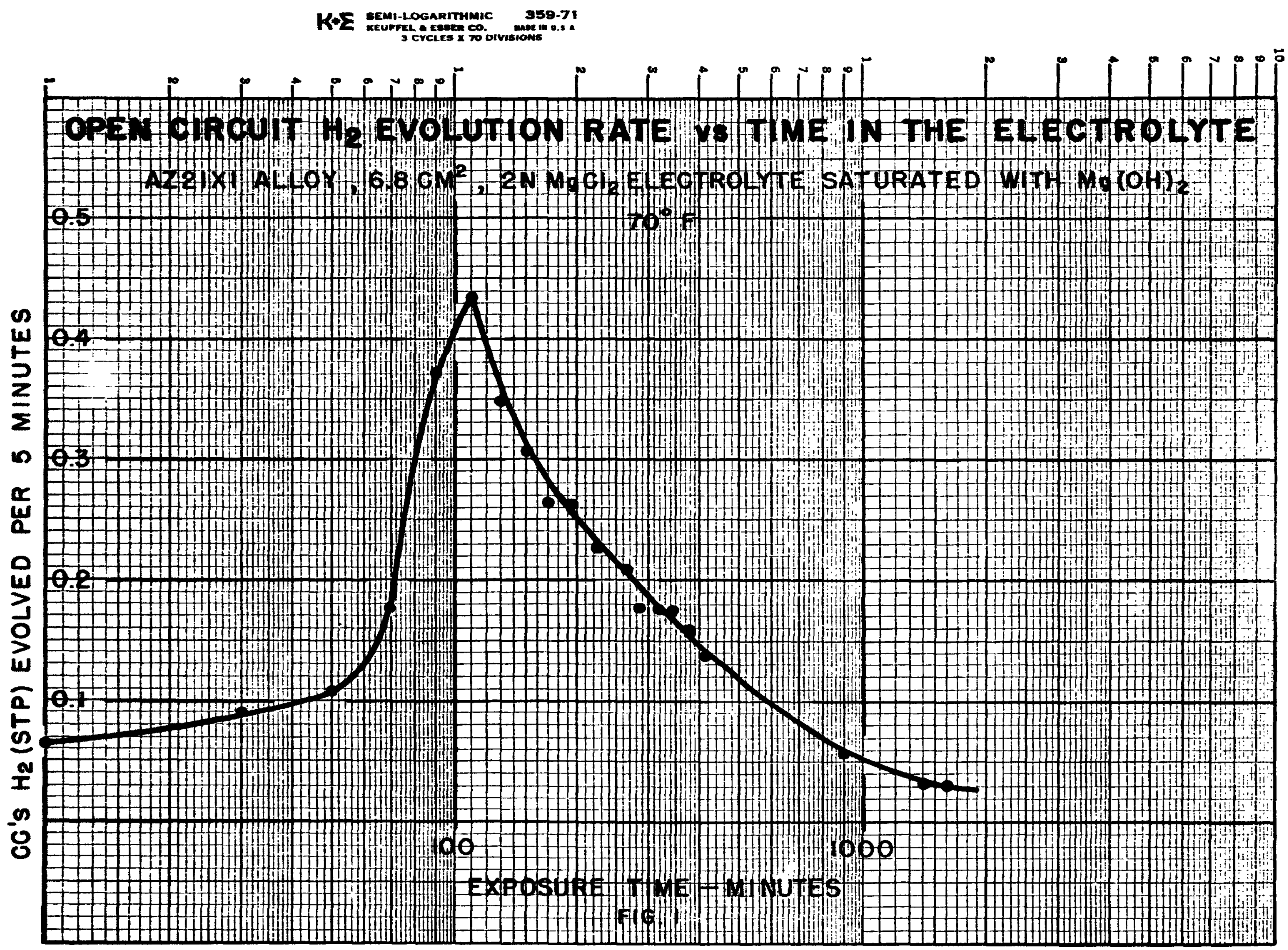
TABLE XXVIII

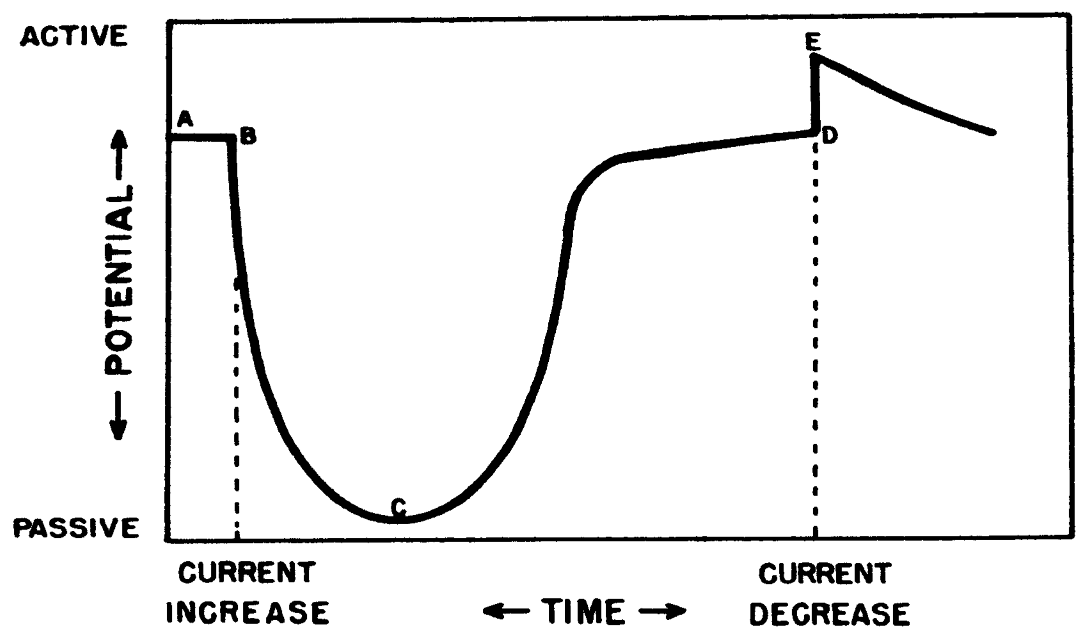
AROMATIC ACID SALT ELECTROLYTES

"D" SIZE CELLS, CONTINUOUS DRAIN, TEMP. 70°F

SALT	NORMALITY	BATCH No.	10 OHMS TO 0.70 VOLTS: VOLTAGE INITIAL C.C.	VOLTAGE AVE. C.C.	HOURS SER.	% EFF.	50 OHMS TO 1.0 VOLTS: VOLTAGE INITIAL C.C.	VOLTAGE AVE. C.C.	HOURS SER.	% EFF.
Mg PHTHALATE	1.66	235216	1.02	0.85	2.5	78	1.55	1.21	32	78
Mg ISOPHTHALATE	2.36	235217	1.00	0.82	1.5	72	1.55	1.25	4	71
			100 OHMS TO 1.0 VOLTS				180 OHMS TO 1.0 VOLTS			
		235216	1.64	1.19	115	78	1.69	1.31	170	73
		235217	1.69	1.33	21	75	1.79	1.22	80	73

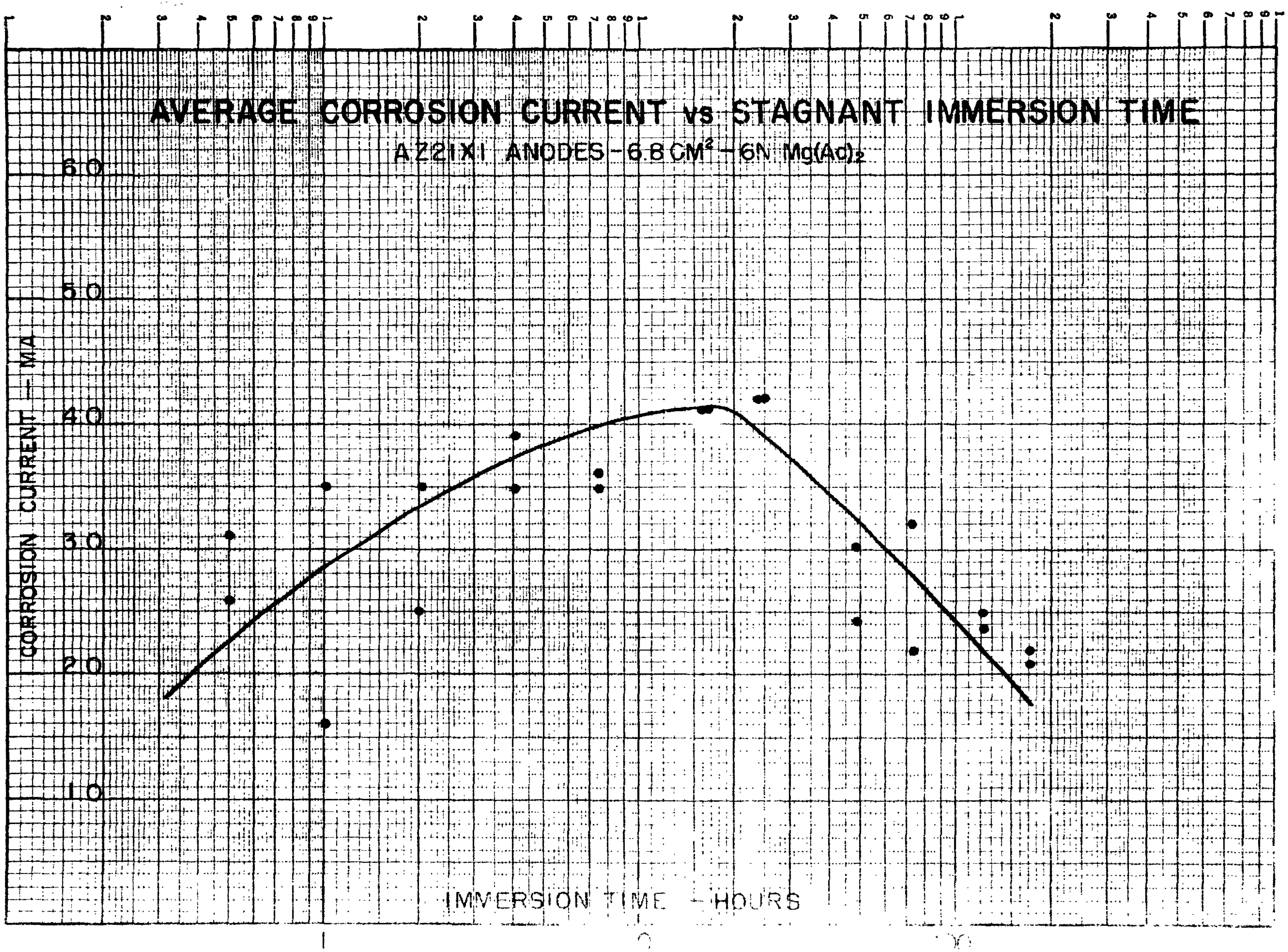
TABLE XXIX

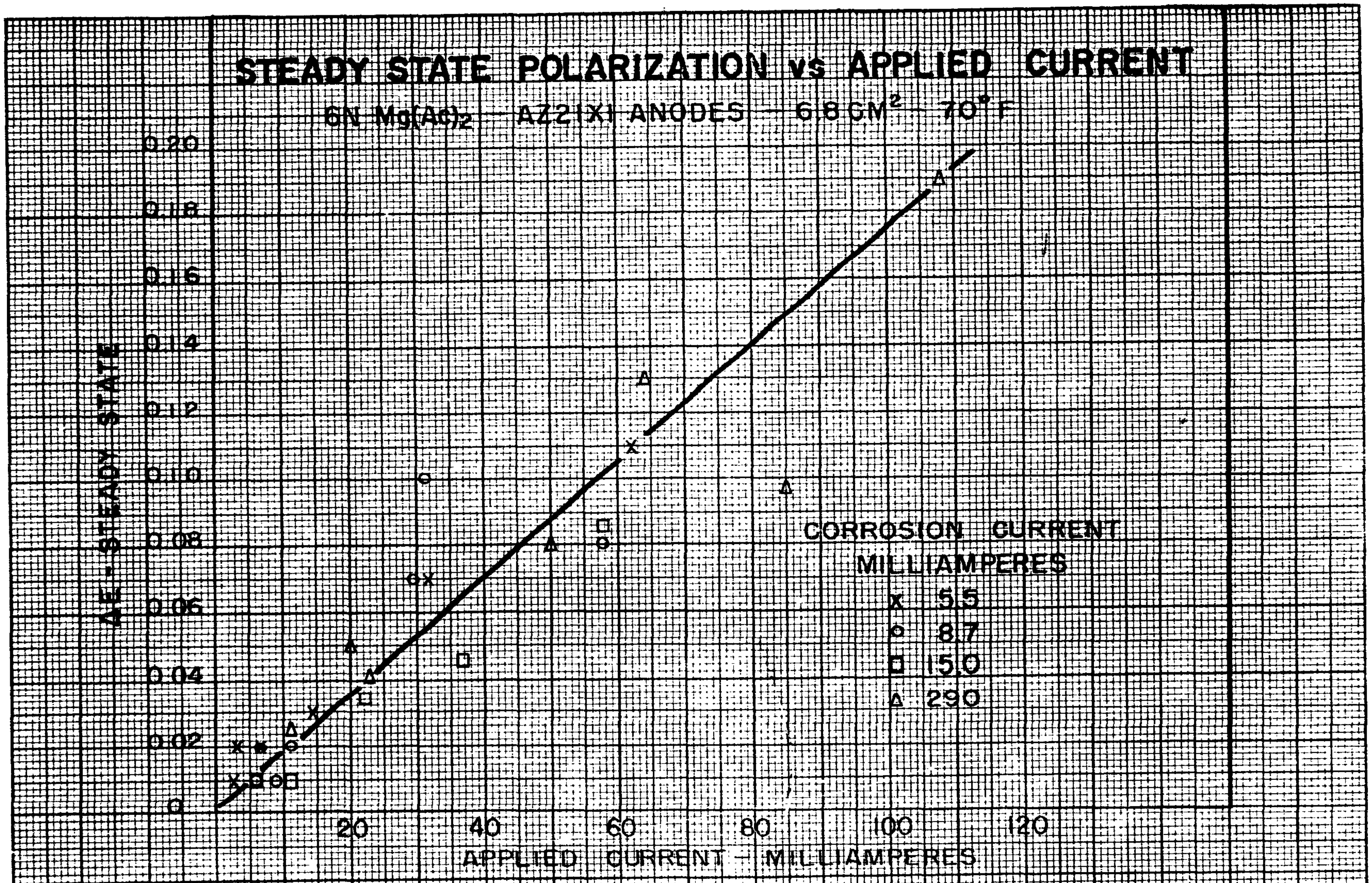

K+E SEMI-LOGARITHMIC 359-71
KEUFFEL & ESSER CO. MADE IN U.S.A.
3 CYCLES X 70 DIVISIONS
OPEN CIRCUIT H_2 EVOLUTION RATE vs TIME IN THE ELECTROLYTE
AZ21X1 ALLOY, 6.8 CM^2, 2N $MgCl_2$ ELECTROLYTE SATURATED WITH $Mg(OH)_2$
70° F
CC'S H_2 (STP) EVOLVED PER 5 MINUTES
0.5
0.4
0.3
0.2
0.1
100
1000
EXPOSURE TIME — MINUTES
FIG. 1



GENERALIZED ANODIC VOLTAGE TRANSIENT
OBSERVED WITH MAGNESIUM

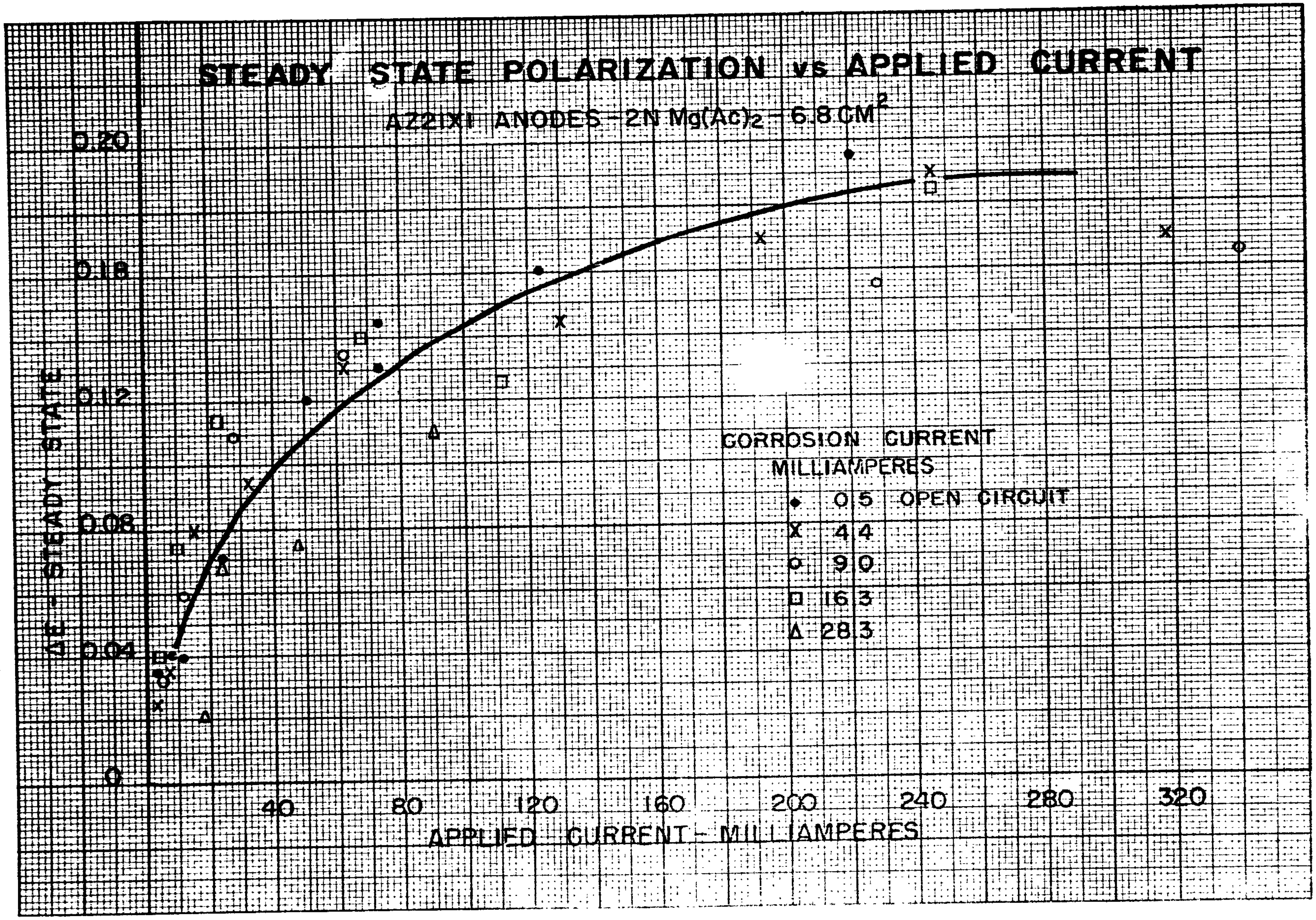
FIG. 2


AVERAGE CORROSION CURRENT vs STAGNANT IMMERSION TIME
AZ21XI ANODES - 6.8 CM² - 6N Mg(Ac)₂
CORROSION CURRENT — MA
6.0
5.0
4.0
3.0
2.0
1.0
IMMERSION TIME — HOURS
1

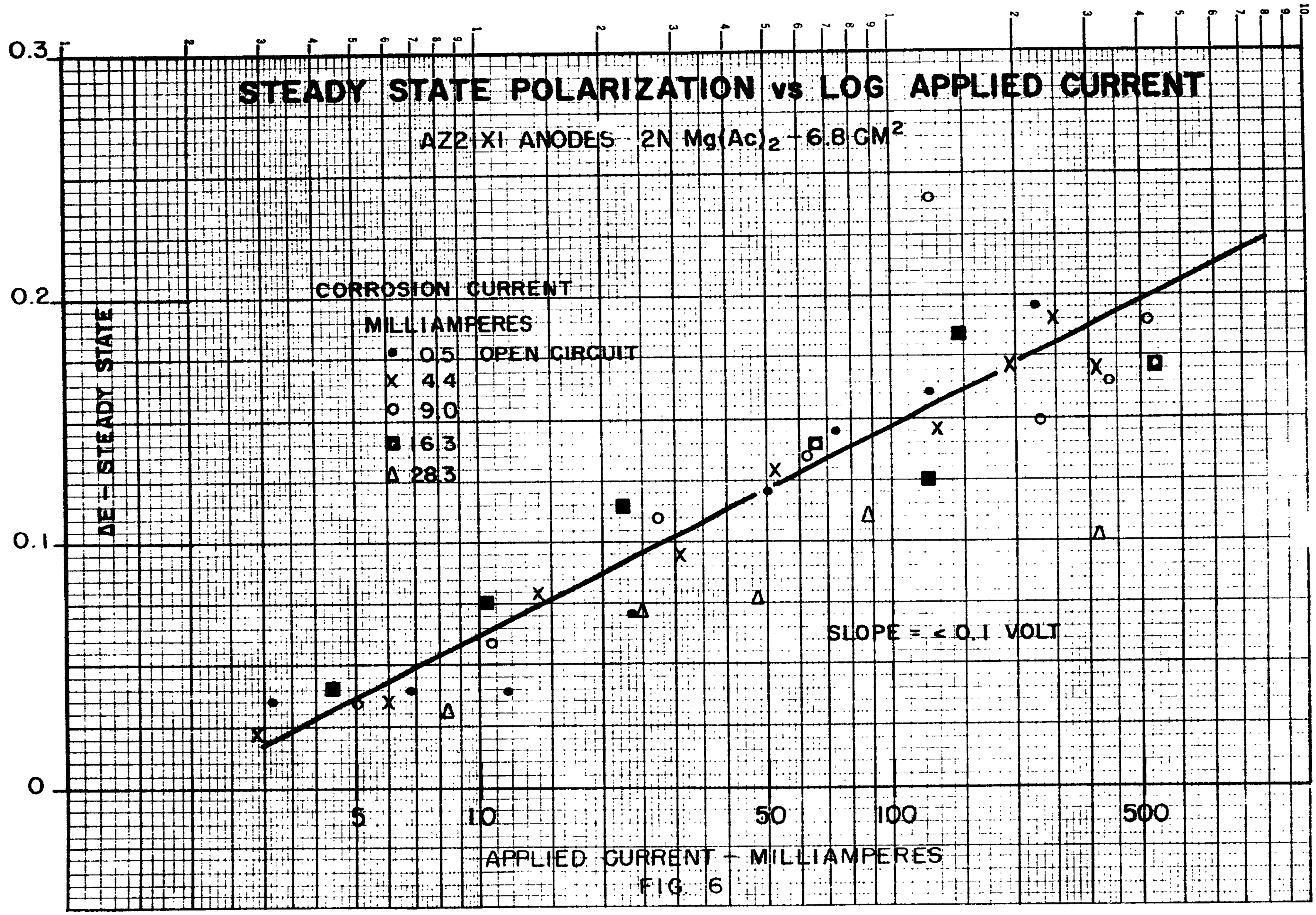


STEADY STATE POLARIZATION vs APPLIED CURRENT
6N Mg(Ac)2 — AZ21X1 ANODES — 6.8 CM2 — 70°F
ΔE - STEADY STATE
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0
20
40
60
80
100
120
APPLIED CURRENT — MILLIAMPERES
CORROSION CURRENT
MILLIAMPERES
X 5.5
o 8.7
□ 15.0
Δ 29.0

FIG. 4



STEADY STATE POLARIZATION vs APPLIED CURRENT
AZ21X1 ANODES - 2N Mg(Ac)2 - 6.8 CM2
ΔE - STEADY STATE
0.20
0.16
0.12
0.08
0.04
0
40
80
120
160
200
240
280
320
APPLIED CURRENT - MILLIAMPERES
CORROSION CURRENT
MILLIAMPERES
0.5 OPEN CIRCUIT
4.4
9.0
16.3
28.3


STEADY STATE POLARIZATION vs LOG APPLIED CURRENT
AZ2 XI ANODES 2N Mg(Ac)2 - 6.8 CM2
CORROSION CURRENT
MILLIAMPERES
• 0.5 OPEN CIRCUIT
X 4.4
o 9.0
■ 6.3
Δ 28.3
SLOPE = < 0.1 VOLT
ΔE - STEADY STATE
0.3
0.2
0.1
0
5
10
50
100
500
APPLIED CURRENT - MILLIAMPERES
FIG. 6

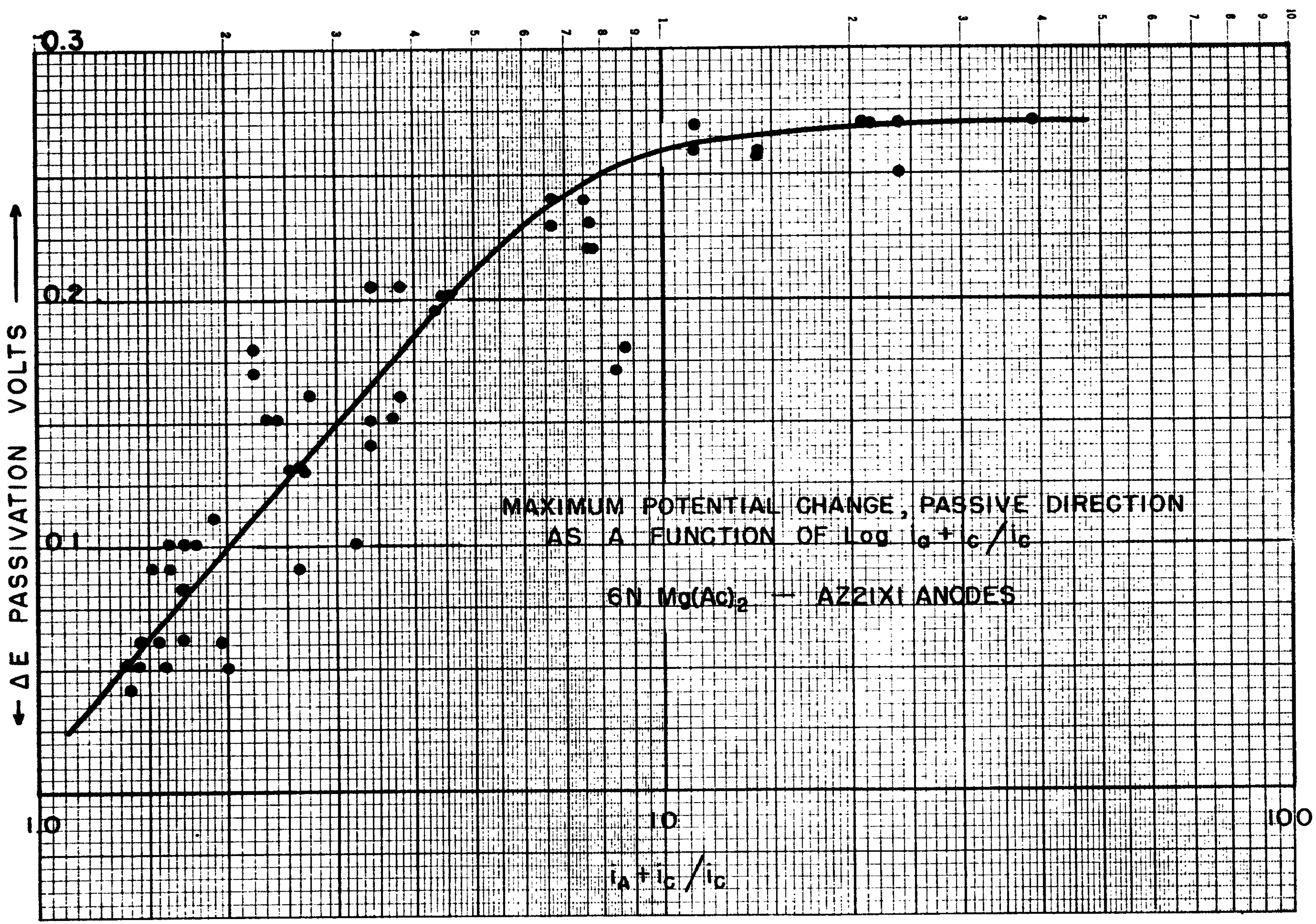

MAXIMUM POTENTIAL CHANGE, PASSIVE DIRECTION
AS A FUNCTION OF Log ia + ic / ic
6N Mg(Ac)2 — AZ21X1 ANODES
← ΔE PASSIVATION VOLTS →
0.3
0.2
0.1
1.0
10
100
iA + iC / iC

FIG. 7

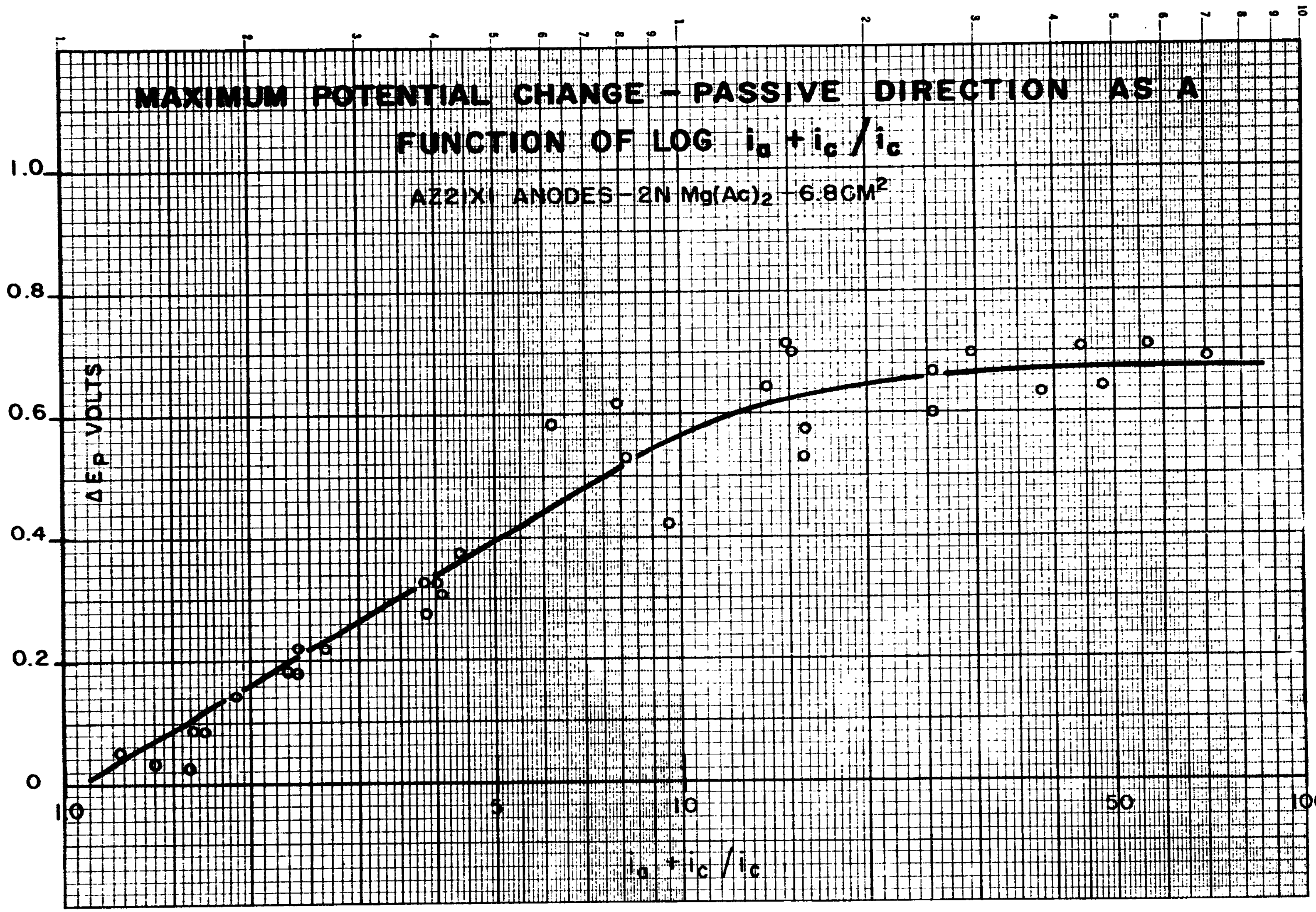

MAXIMUM POTENTIAL CHANGE – PASSIVE DIRECTION AS A FUNCTION OF LOG $i_a + i_c / i_c$
AZ21XI ANODES – 2N $Mg(Ac)_2$ – 6.8 CM^2
ΔE_P VOLTS
1.0
0.8
0.6
0.4
0.2
0
1.0
5
10
50
100
$i_a + i_c / i_c$

FIG. 8

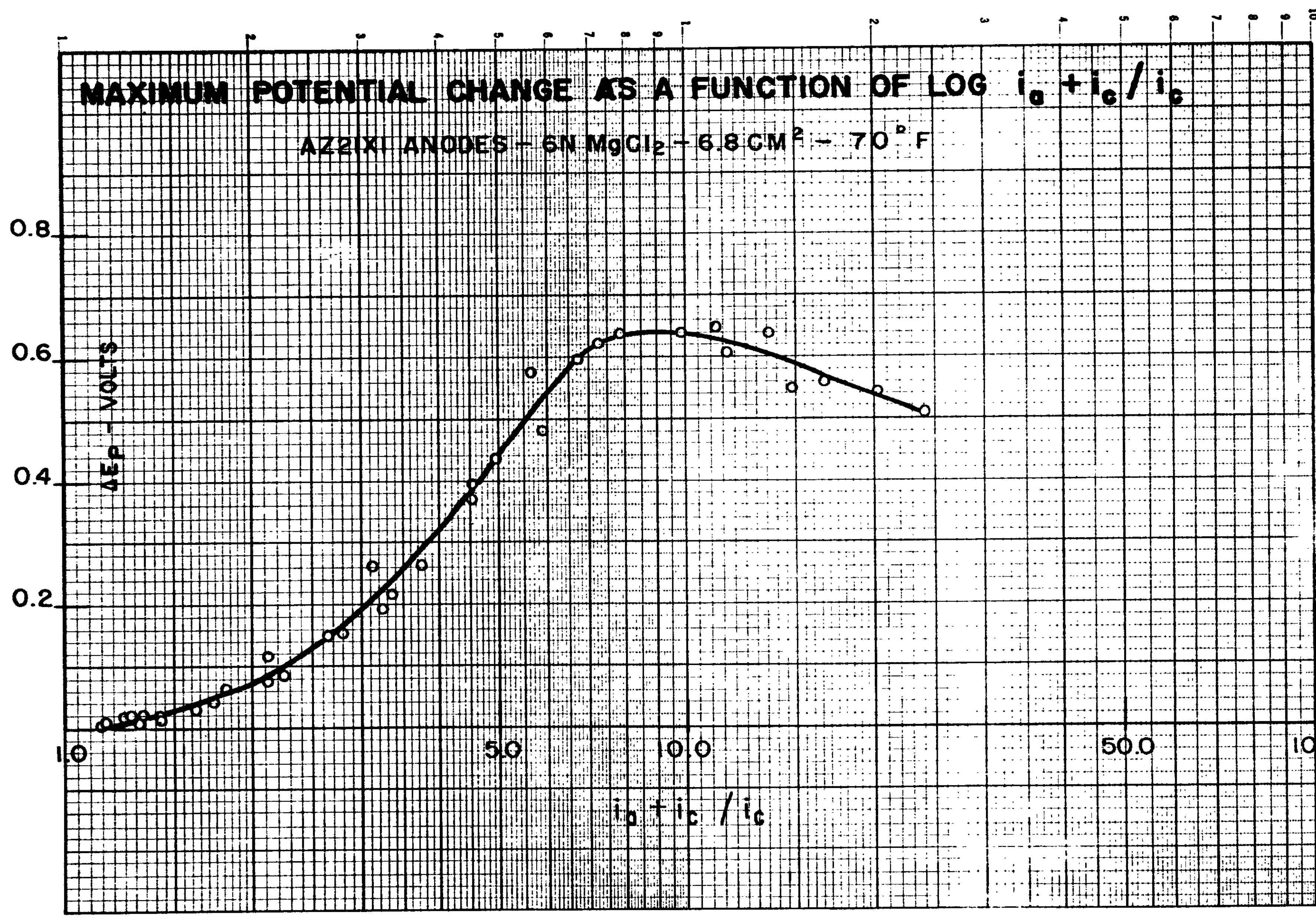
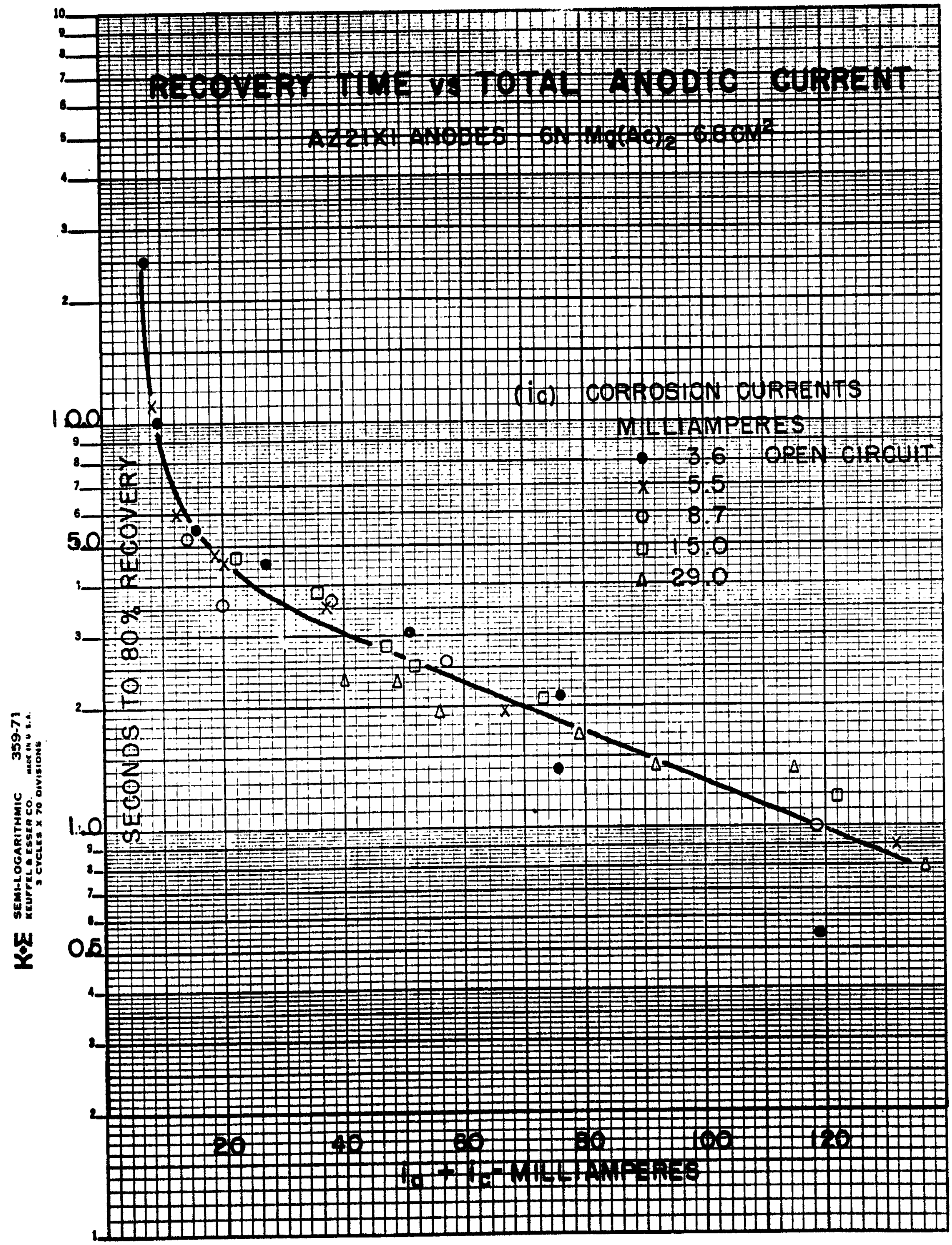
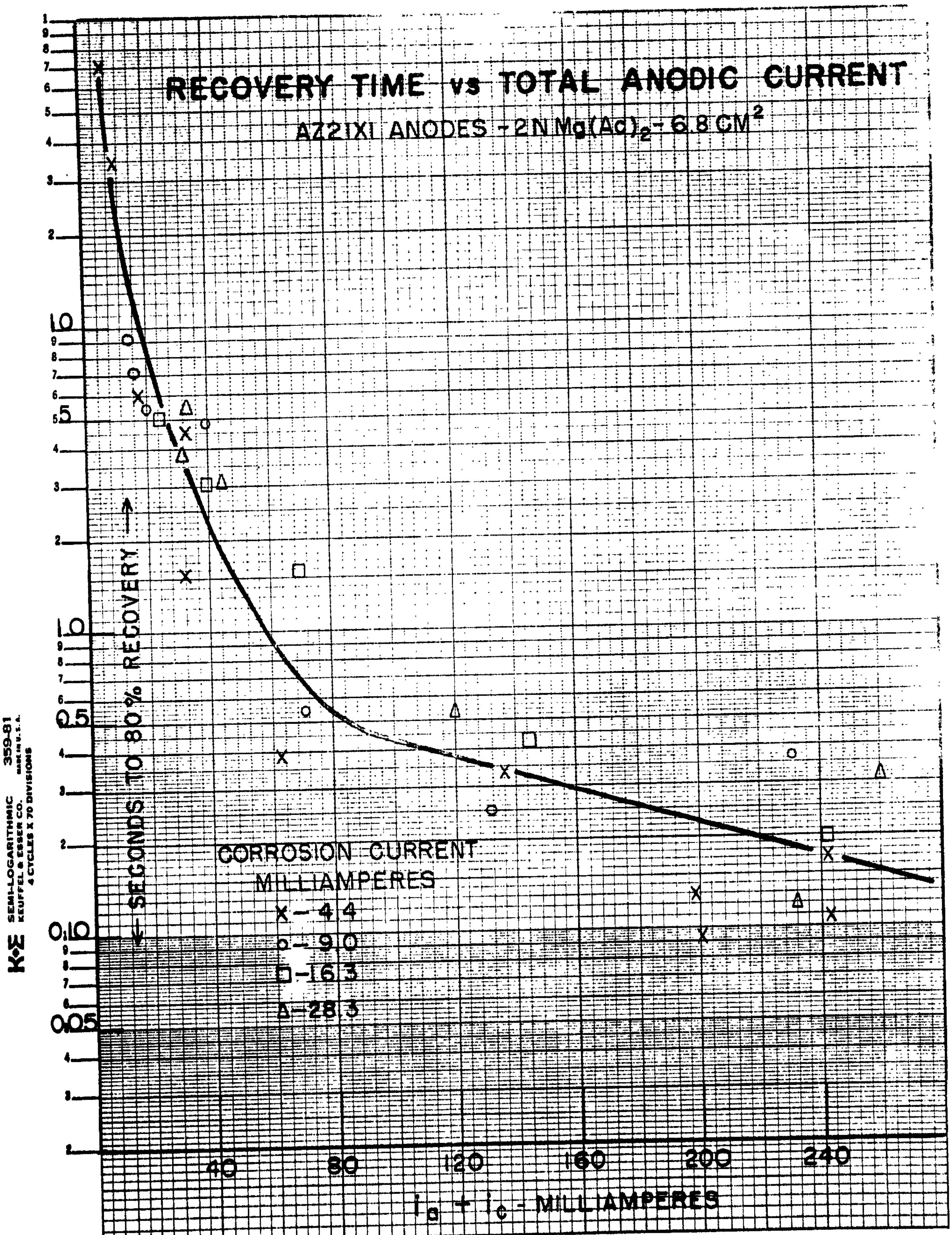

MAXIMUM POTENTIAL CHANGE AS A FUNCTION OF LOG $i_a + i_c / i_c$
AZ21XI ANODES - 6N $MgCl_2$ - 6.8 CM^2 - 70° F
ΔE_p - VOLTS
0.8
0.6
0.4
0.2
1.0
5.0
10.0
50.0
100
$i_a + i_c / i_c$

FIG. 9



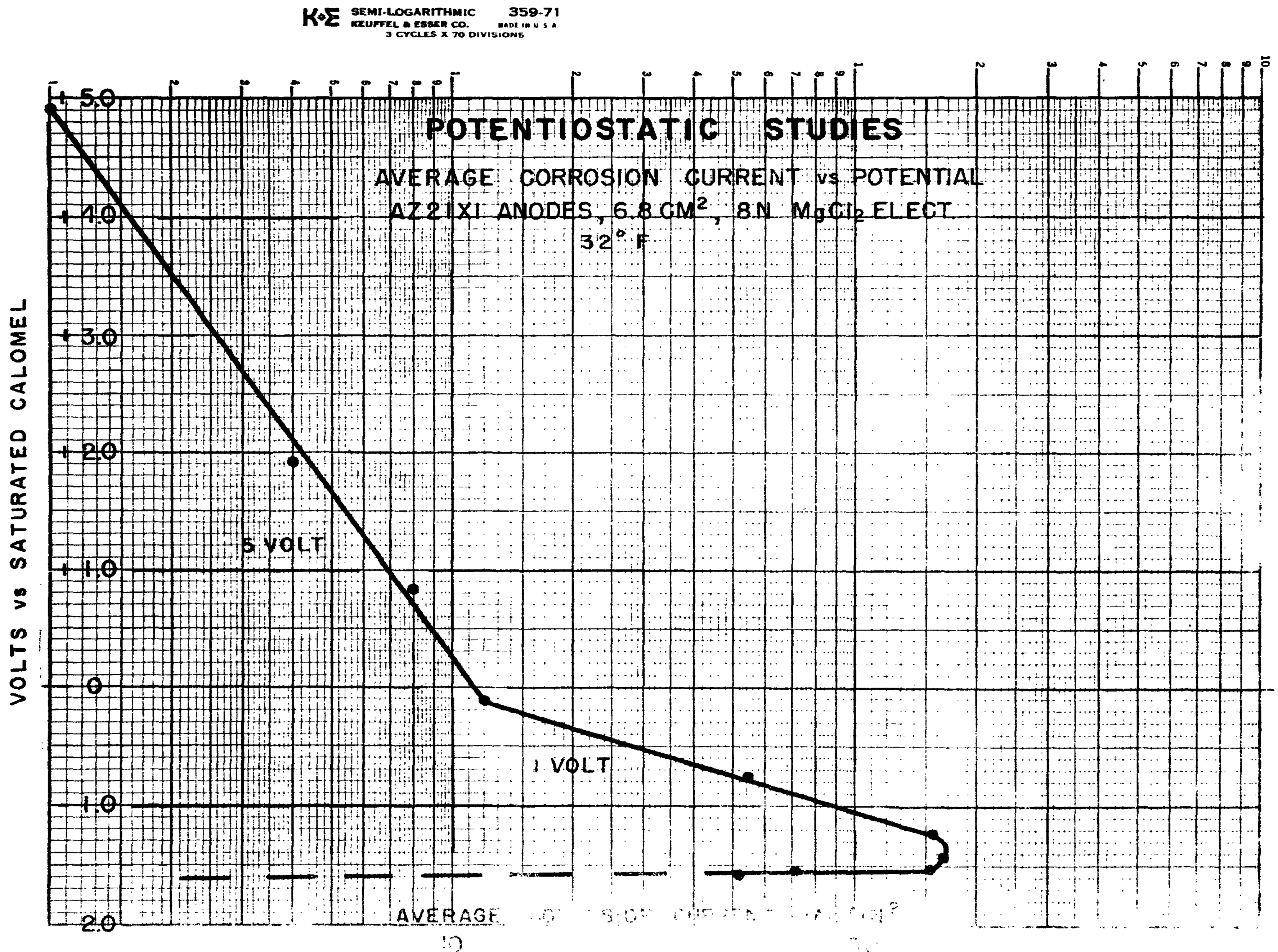
RECOVERY TIME vs TOTAL ANODIC CURRENT
AZ21X1 ANODES 6N $Mg(Ac)_2$ 6.8 CM^2
(ic) CORROSION CURRENTS
MILLIAMPERES
● 3.6 OPEN CIRCUIT
x 5.5
o 8.7
□ 15.0
Δ 29.0
SECONDS TO 80% RECOVERY
10.0
5.0
1.0
0.5
20
40
60
80
100
120
$i_a + i_c$ - MILLIAMPERES
K&E SEMI-LOGARITHMIC 359-71
KEUFFEL & ESSER CO. MADE IN U.S.A.
3 CYCLES X 70 DIVISIONS

FIG. 10



RECOVERY TIME vs TOTAL ANODIC CURRENT
AZ21X1 ANODES - 2N Mg(Ac)$_2$ - 6.8 CM^2
SECONDS TO 80% RECOVERY
CORROSION CURRENT
MILLIAMPERES
X - 4.4
o - 9.0
□ - 16.3
Δ - 28.3
$i_a + i_c$ - MILLIAMPERES
10
5
1.0
0.5
0.10
0.05
40
80
120
160
200
240
K·E SEMI-LOGARITHMIC 359-81
KEUFFEL & ESSER CO.
4 CYCLES X 70 DIVISIONS

FIG. 11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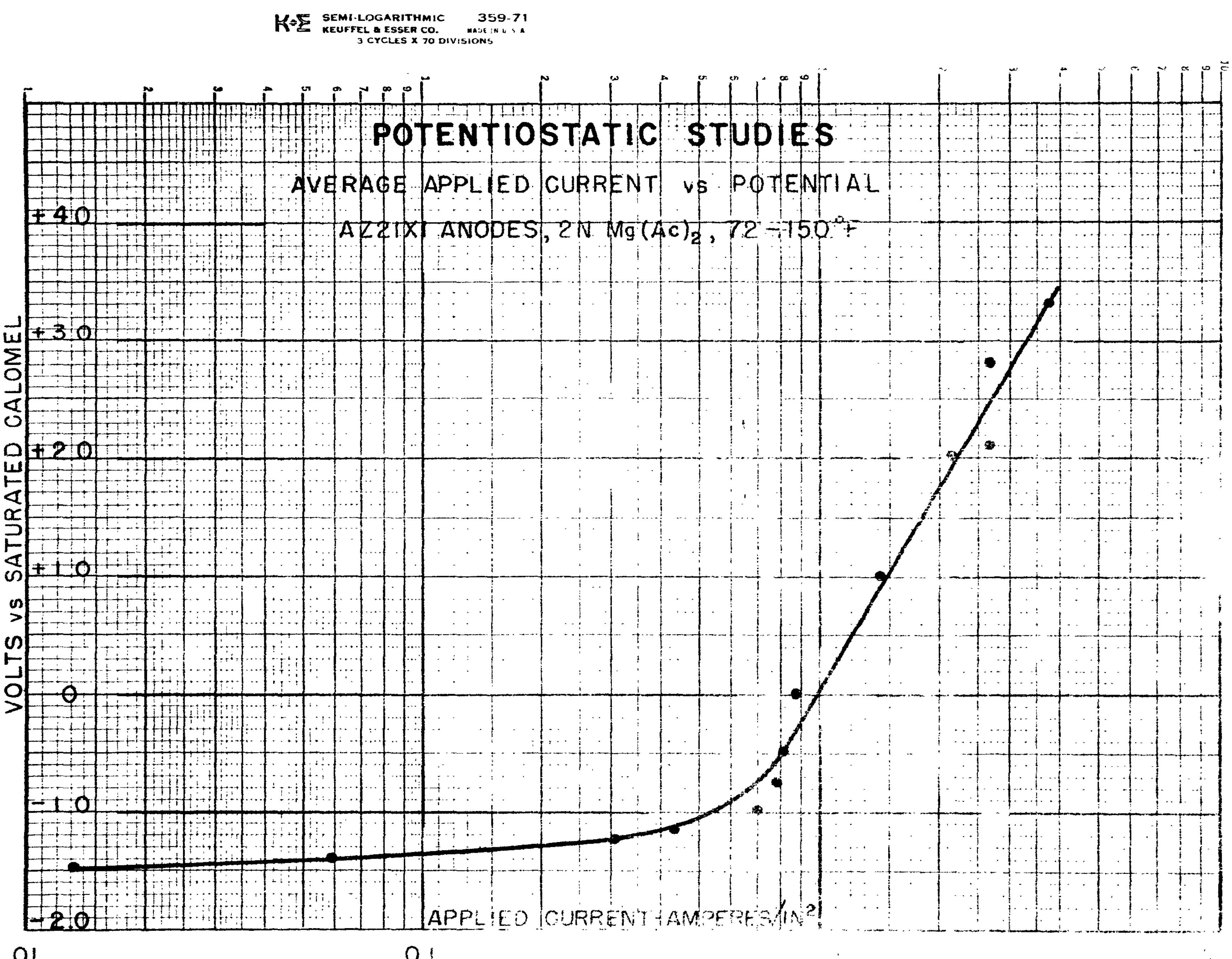
POTENTIOSTATIC STUDIES
AVERAGE CORROSION CURRENT vs POTENTIAL
AZ21XI ANODES, 6.8 CM², 8N MgCl₂ ELECT.
32° F
5 VOLT
1 VOLT
VOLTS vs SATURATED CALOMEL
+5.0
+4.0
+3.0
+2.0
+1.0
0
1.0
2.0
AVERAGE
10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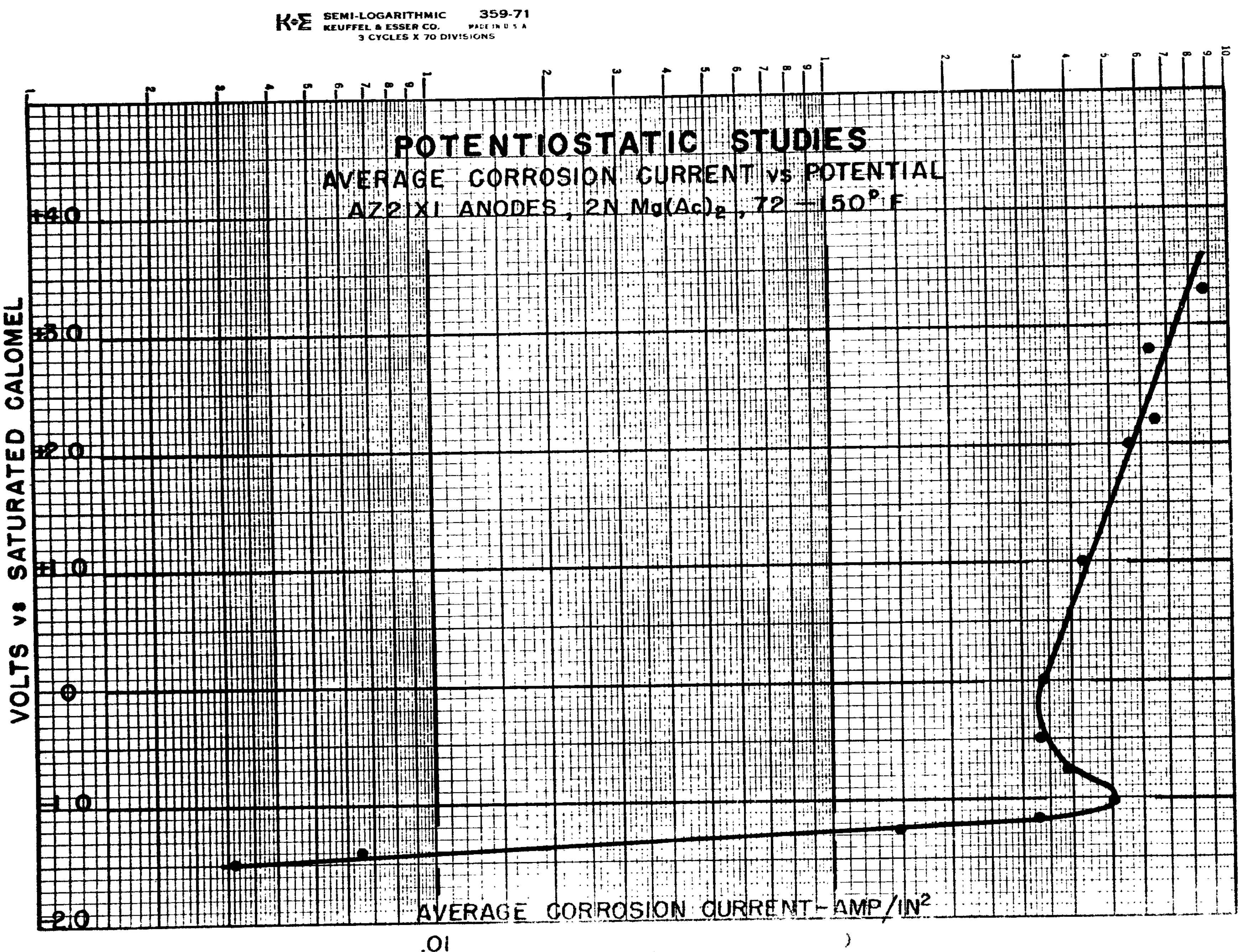
POTENTIOSTATIC STUDIES
AVERAGE APPLIED CURRENT vs POTENTIAL
AZ21XI ANODES, 2N Mg(Ac)2, 72 - 150°F
VOLTS vs SATURATED CALOMEL
+4.0
+3.0
+2.0
+1.0
0
-1.0
-2.0
APPLIED CURRENT AMPERES/IN2
.01
0.1



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POTENTIOSTATIC STUDIES
AVERAGE CORROSION CURRENT vs POTENTIAL
AZ21XI ANODES, 2N Mg(Ac)2, 72 - 150° F
VOLTS vs SATURATED CALOMEL
+4.0
+3.0
+2.0
+1.0
0
-1.0
-2.0
AVERAGE CORROSION CURRENT - AMP/IN2
.01

INDEX CARD

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Investigation of the Magnesium Anode
by J. L. Robinson

Third Quarterly Progress Report,
1 January 1963 to 1 April 1963
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DA Proj. No. 3A99-09-001-02
Unclassified Report

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2. Magnesium Dry Cells

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